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PROJECT NO. 2235

AIR-TO-GROUND VISUAL SIMULATION DEMONSTRATION

FINAL REPORT

VOLUME 1 OF 2

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PREFACE

Project 2235 was structured in three phases. Phase I was the technical evaluation phase, Phase II was the operational evaluation phase and Phase III was the reporting phase. The report documents project activities and results in two volumes. Volume 1 documents Phase III, the reporting phase. It contains an executive summary, results of Phase I and II, and an analysis of those results, conclusions and recommendations. Volume 2 documents the detailed procedures and methods used during Phase I and II. Engineering data obtained during Phase I is also contained in Volume 2. This volume documents Phase III efforts.

Valuable and cost-effective aircrew training using image simulation has been thoroughly established by its use for many years. The major area of application, however, has been for training aircrews of multicrew aircraft. Visual flight simulation, applicable to fighter/attack mission, has remained virtually unexplored. The introduction of new fighter/attack aircraft into the operational inventory is but one of many factors influencing increased interest and focusing attention on the feasibility of visually simulating environments for the fighter/attack mission. Project 2235 is a result of increased interest and was an ambitious step toward exploring this application of visual simulation.

This project could not have been completed without the dedicated efforts and team work of numerous persons within the following participating organizations:

Air Force Human Resources Laboratory (AFHRL)
Air Force Flight Dynamics Laboratory (AFFDL)
Aeronautical Systems Division, Directorate of Equipment Engineering, Visual and Electro-Optical Branch (ASD/ENETV)
58 Tactical Fighter Training Wing
33 Tactical Fighter Wing
35 Tactical Fighter Wing
23 Tactical Fighter Wing
355 Tactical Fighter Wing
Chief of Naval Air Training (N-2)
The Singer Company

The authors wish to express their appreciation to all those persons in the above named organizations for their contributions.

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TERMS AND ABBREVIATIONS

AAA	Anti Aircraft Artillery
AOI	Area of Interest
APL	Average Picture Level
ASUPT	Advanced Simulator for Undergraduate Pilot Training
CCTV	Closed Circuit Television
CIG	Computer Image Generation, also termed CGI
CRT	Cathode Ray Tube
DOF	Degrees of Freedom
FAC	Forward Air Controller
fl	Foot lambert
GE	General Electric
LAMARS	Large Amplitude Multi Mode Aerospace Research Simulator
MTF	Modulation Transfer Function
RGS	Raster Graphics System
SAAC	Simulator for Air-to-Air Combat
SEL	System Engineering Laboratories
SOA	State-of-the-Art
SAM	Surface-to-Air Missile
STG	Synthetic Terrain Generator
TAC	Tactical Air Command
3-D	Three Dimensional
2-D	Two Dimensional
TMB	Terrain Model Board
TV	Television

GLOSSARY

Area of Interest - A segment of a visual display normally square or rectangular, which contains a high resolution terrain video presentation of some feature, such as terrain or airborne targets. The remainder of the display can be low resolution supporting information such as featureless sky/earth or sky/checkerboard patterns.

Bit - A single character of a digital word, either one or zero, used in the computer to indicate the condition, sign or quantity of that particular segment of the word.

Bowing - Describes an optical condition where a straight line bends when traversing juxtaposed CRT joints.

Brightness - Measurement of the amount of light emitted from the CRT Face or the available light displayed after passing through the optical chain. Expressed in foot lamberts.

Byte - Several bits of information, taken from a computer word, used to indicate a quantity, nemonic code or some other specialized meaning. Used to increase computer efficiency.

Collimation Errors - Errors which cause objects to appear nearer or farther than infinity when viewed through infinity (virtual image) optics display packages.

Contrast - The ratio between the brightness of the brightest highlight in a display and that of the dimmest gray shade. Shading effects should be accounted for or eliminated when measuring contrast.

Critical Mach Number - Speed at which the first sonic shock waves start to form on the aircraft.

Degrees of Freedom - Used to express motion platform movement along and about the three aircraft axis. Movement along the X, Y and Z axis is expressed as longitudinal lateral and vertical translation, and about the three axis as roll, pitch and yaw.

Edge - The straight line segment between two vertices.

Environmental Data Base - The entire collection of models (defined numerically in three-dimenstional vector space) used to simulate a visual environment.

Field of View - Total display surface available for pilot viewing. Expressed in angular measures, i.e., $\pm$ degrees horizontal and vertical, from the X axis of the aircraft.

Foul - Air-to-ground weapons delivery term used to define a condition wherein a pilot fires inside a minimum safe firing range (2000') during strafe pass or recovers below a minimum altitude on a bomb or strafe pass.

Gray Scale - A series of gray patches increasing in brightness from black to white.

Gray Shade - One of the 1024 levels of brightness available on a CRT.

Gunsight - A cockpit mounted device used to aid the pilot in aiming the aircrafts' gun. Standby, fixed, or iron gunsights are manually depressible by the pilot and not computer controlled.

High Risk - That associated with the research and development of new technology or new applications of existing technologies. Has a significant probability of not reaching total design goals. Cost and time estimates are unreliable.

Iteration Rate - Term which expresses the frequency of a computer program (i.e., 20 interations per/second).

Limiting Resolution - That spatial frequency on a resolution wedge beyond which the individual resolution lines are not visible. This point on a resolution wedge is very indefinite and subject to wide variation among different observers. A more consistent figure for limiting resolution is obtained by specifying the spatial frequency beyond which the MTF curve drops below a given value, usually 5%.

Line Pair - A pair of adjacent black and white lines. This term is used in optical rather than video systems.

Linear Gray Scale - A series of gray patches which has a constant brightness difference between any two adjacent patches. The logarithmic response of the human eye makes the lighter shades of linear gray scale appear much closer together than the darker shades.

Logarithmic Gray Scale - A series of gray patches which has a constant brightness ratio between any two adjacent patches.

Low Risk - That associated with the integration or minimum modification of off-the-shelf equipment commensurate with production programs. Has a high probability of reaching design goal within cost and time estimates.

Medium Risk - That associated with major modifications to existing technologies (engineering development). Has a significant probability of reaching design goals. Cost and time estimates are fairly reliable.

Mil - Unit of angular measurement equal to 1/6400 of the circumference of a circle.

Model - An approximation of some feature (e.g., a truck) by the use of straight line segments or "edges".

Modulation Transfer Function (MTF) - A spatial frequency response curve for electro-optical systems.

Optical Mosaic - System which incorporates more than one CRT to expand the field of view. CRTs are normally situated in such a way so as to have no gaps between CRT joints. (Juxtaposed.)

Perspective - The ability of visual systems to present depth and distance cues.

Raster - The left to right, top to bottom pattern of the CRT Electron Beam. Modulation of the beam by video signal causes activation of CRT faceplate phosphor resulting in recognizable images being generated.

Resolution - Term used to express the ability of a system (generation or display) to faithfully reproduce an image.

Resolution Wedge - A collection of alternating black and white lines (usually four black and three white) which decrease in width from one end to the other thus forming a wedge. The line width at any point on the wedge is usually marked to show how many lines of that width (counting both black and white) would fit into a distance equal to the TV raster height.

Scan Line - One line of the raster, left to right.

Shading - Variation in brightness over the surface of a display when the original scene is of even brightness. Displays are typically less bright at their corners and edges than they are at the center.

Sight - Gunsight. A hardware device mounted in the cockpit in front of the pilot which he uses to determine aircraft alignment for bombing and strafing.

Sight Reticle - Illuminated set of concentric circles in the gunsight.

Spatial Frequency - The number of TV lines per some unit distance or per unit viewing angle. These measures may be inverted to show the distance per single TV line or the viewing angle per single TV line.

Synergistic Motion System - A motion system in which movement along or about any one axis requires movement of all six hydraulic actuators.

TV Line - One line of a resolution wedge (black or white).

SECTION I

SUMMARY

1. BACKGROUND

In recent years the cost of training in actual aircraft and the inherent limits placed on inflight training have increased dramatically, thus creating added incentives to introduce the use of visual simulation in training programs. The capability of visual simulation to provide effective training for certain tasks, such as takeoff, approach and landing, has been thoroughly established in airline training programs. However, the use of simulation for other tasks, such as weapons delivery and tactical operations, has been restricted since simulators have not had adequate imagery in conjunction with a sufficient field of view (FOV). In 1973, the Tactical Air Command (TAC) submitted requirements for A-10 aircrew training devices which included a full range of equipment from study carrels to full mission simulators. The A-10 Trade Study indicated that this full range of training devices was considered to be the minimum required for an efficient operational training program that was cost effective.

a. A-10 Trade Study

Due to fiscal and time constraints, actions were taken to explore various alternatives to TAC's simulator requirements as stated in December 1973. The result was the A-10 Trade Study published in April 1975, which indicated that the most effective and efficient simulators, listed in descending order of cost and training effectiveness, were the full mission simulator, a weapons delivery simulator, and an instrument flight simulator.

b. Direction For Project 2235

Since neither air-to-ground weapons delivery simulation nor full mission simulation had been thoroughly demonstrated, a production program for these types of visual simulators was considered to have an unacceptably high risk. As a result the 16 April 1975 A-10 Program Management Directive (R-P 3034(4)/64225F) initiated this evaluation of the visual simulation technologies that were applicable to air-to-ground weaponry tasking.

2. PURPOSE

To evaluate and report the technical feasibility of air-to-ground visual simulation as demonstrated by current technologies. This report provides the criteria, results, conclusions, and recommendations of that evaluation for use in the A-10 full mission simulator procurement decisions and subsequent programs.

3. SCOPE AND LIMITING FACTORS

a. Scope

The scope of Project 2235 consisted of an Operational and Technical evaluation of three candidate visual research simulators. The tasks evaluated were primarily directed towards conventional and tactical air-to-ground weapons delivery.

Those areas determined to be outside of the scope of the project were as follows: an evaluation of full mission simulation capabilities, transfer of training studies, reliability and maintainability analysis, and cost-effectiveness determinations.

b. Limiting Factors

The systems selected for the evaluation were modified to the extent considered necessary for the evaluation. Priority was given to efforts which would enable the air-to-ground role to be accomplished. Emphasis was placed throughout the operational evaluation on air-to-ground tasks; however, if a particular system possessed the capabilities to allow the performance of other tasks (i.e., takeoff, landing, formation, etc.), then such tasks were explored. Although the subject of this report is visual system technology, it was not feasible to control the effects of all variables (i.e., order of evaluation or motion effects) on the pilot subjects. No attempt to evaluate the effect of these influences was made during this evaluation. Rather, an attempt was made to control these influences by such methods as returning to the first device evaluated for an additional sortie and providing each pilot with an equal amount of task performance with and without motion.

Since it was not intended or practical to modify each system to the same standards, the data collected was not intended for nor has it been used for a comparison of the systems evaluated. The data has been used to describe the capabilities of each technology evaluated. The potential capability of each technology beyond that demonstrated was established by respective systems engineers and then reassessed by operational pilots. All subsequent analysis and conclusions have been based upon both the demonstrated and potential capability.

4. GENERAL SYSTEMS DESCRIPTIONS

A visual simulator must have at least two basic characteristics in order to provide an air-to-ground capability. The first is the ability to generate an appropriate visual image containing geographic and cultural information; the second is the ability to dynamically display this information in a format which allows unaltered task performance by the pilot. For this project, a third basic requirement existed; the availability of the devices within the time limitations of the evaluation. The first three devices described below fulfilled the requirements and constituted the original scope of the evaluation. A fourth device (2B35) was added to the evaluation schedule in order to evaluate the effects of specific capabilities (i.e., color, ground texture, etc.) which were not available on all of the other devices. Detailed engineering descriptions of each device are provided in Section II.

a. Advanced Simulator for Undergraduate Pilot Training (ASUPT)

The ASUPT simulator was built as an advanced research device for the Human Resources Laboratory, Flying Training Division at Williams AFB, Arizona. It was developed to investigate the simulator's role in future Undergraduate Pilot Training programs. It consists of two simulator cockpits representing the T-37 aircraft. Each independent cockpit is mounted on a six degree-of-freedom (DOF), synergistic motion platform with additional kinesthetic cues provided by a G-seat (Figure I-1). The display imagery is a computer image generated (CIG), two-dimensional perspective image of a three-dimensional environmental model stored as numerical data in computer memory and displayed as television video. Significant software and hardware modifications were necessary to provide expanded system capability for this project. Special algorithm development and implementation of software programs were required to generate weapons trajectories, ordnance effects, moving model paths, and weapons delivery scoring. A special environmental data base was designed.

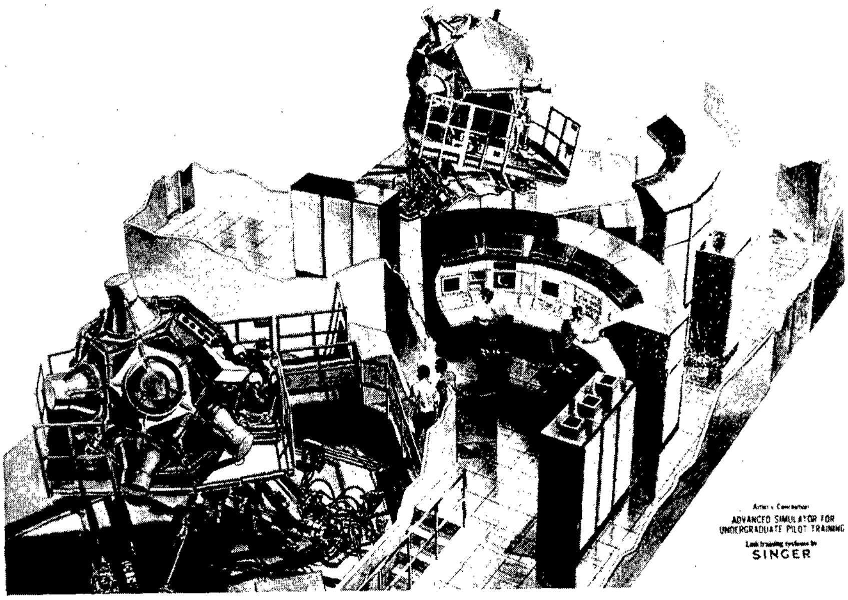


FIGURE I-1 ASUPT

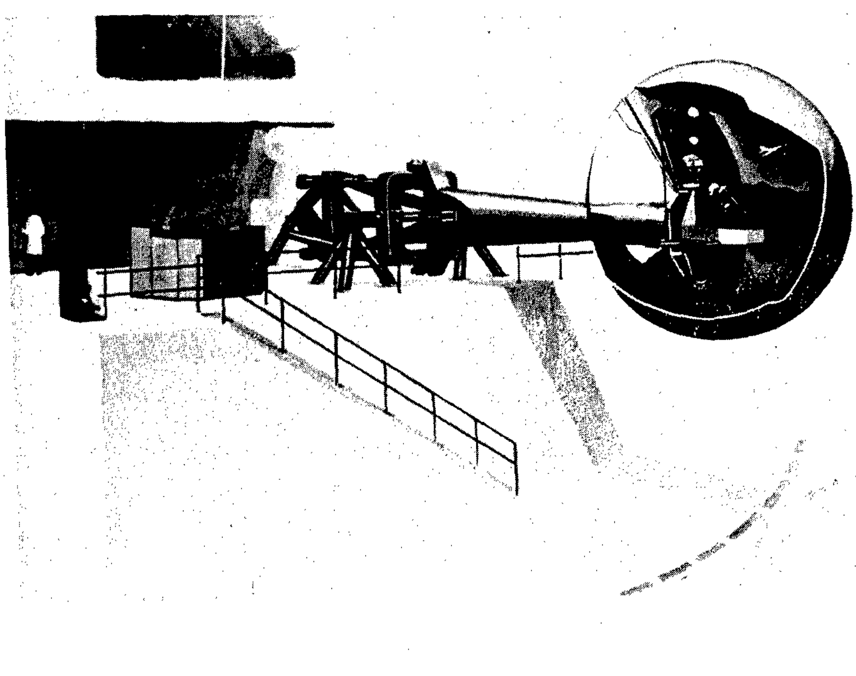


FIGURE I-2 LAMARS

The environmental data base or gaming area was 36 nautical miles by 36 nautical miles and included an airfield complex, a conventional gunnary range modeled after a Gila Bend range and two tactical areas. The additional software required a moving head disk drive and supplementary computer core memory. In addition, an optical gunsight was installed. The visual display is a mosaic composed of seven 36 inch monochrome Cathode Ray Tubes (CRTs) viewed through pentagonal in-line infinity optical windows (pancake windows) in a dodecahedron configuration. The configuration allows the CIG images to be displayed throughout the entire FOV (+150° horizontal and +110° -40° vertical). This system will hereafter be referred to by the image generation and display technology it utilizes (i.e., CIG/Optical Mosaic).

b. Large Amplitude Multi-Mode Aerospace Research Simulator (LAMARS)

The LAMARS is an engineering flight simulator built to be used in flight dynamics research, prototype aircraft evaluation, and weapon system development. It is located in the Air Force Flight Dynamics Laboratory at Wright-Patterson AFB, Ohio. The LAMARS has a single cockpit containing representative flight instrumentation in a fighter type configuration. The cockpit is mounted at one end of a 30 foot horizontal beam providing five DOF motion (Figure I-2). Other kinesthetic cues are provided by a G-suit. The display imagery is generated by a physical model viewed by a television camera through an optical probe and is presented to the pilot by a real-image projector. The physical model can be either an aircraft or a Terrain Model Board (TMB). For this project, the terrain image was used (Figures I-3, 4). It was generated by a system consisting of a large full color three-dimensional model (TMB) of geographic and cultural features, including urban areas, rural terrain, a surface-to-air missile (SAM) site, an airport complex, a dive bomb circle, and a strafe panel. The visual display system consists of a 20-foot diameter spherical projection screen fixed to the beam. Two projectors within the sphere displayed the visual information to the pilot. A real image (television) projector provided the high resolution monochrome terrain Area of Interest (AOI) in rectangular 36° by 48° format while the sky/earth projector used a point light source to provide a well defined horizon throughout the sphere (+133° horizontal and +108° vertical FOV). Two methods were used to dynamically position the AOI - the first was to slave the optical probe and camera

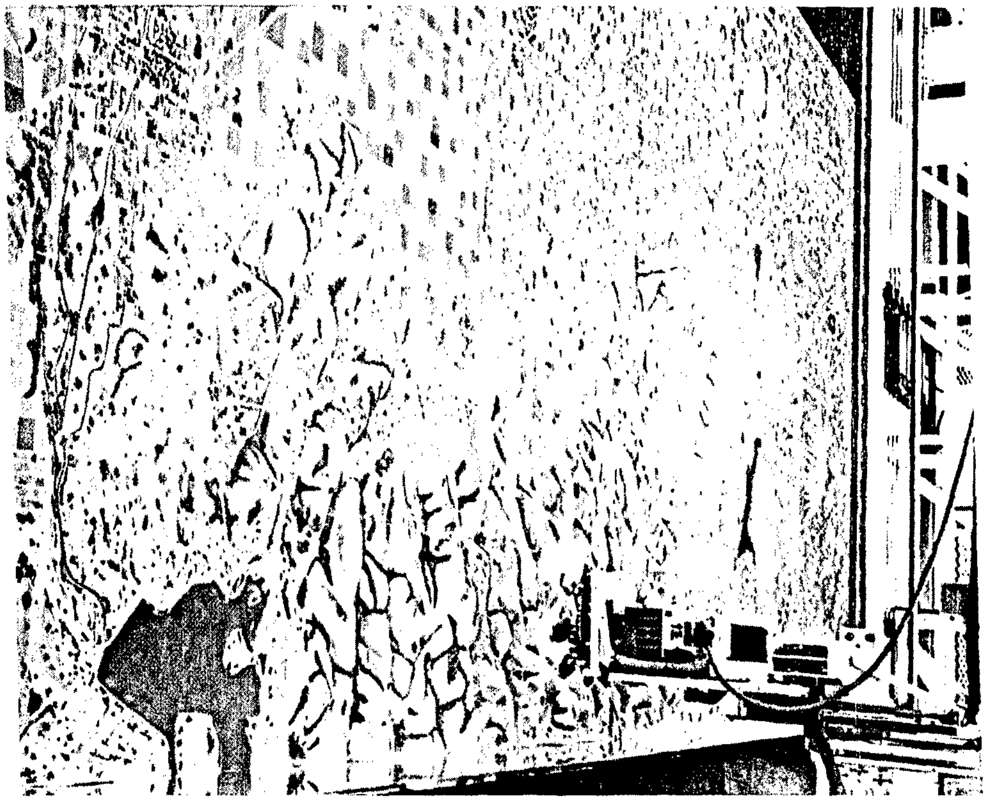


FIGURE I-3 LAMARS TERRAIN MODEL BOARD

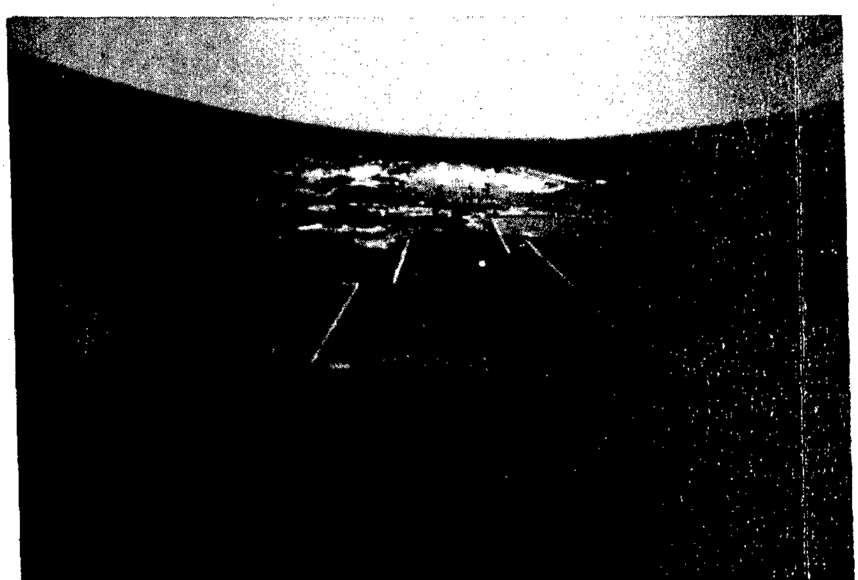


FIGURE I-4 LAMARS AREA OF INTEREST (AOI) DISPLAY to the pilot's head as well as to the aircraft, thus allowing him to look about within the sphere and view a correctly oriented visual segment. To accomplish this, a state-of-the-art (SOA) helmet mounted sight system was used to control the placement of the AOI. The second approach was to fix the visual scene to a specific point or target on the terrain board. This permitted the 60° diagonal AOI to migrate within the sphere based on the relative position of the aircraft to target. Finally, special software programs were developed for weapon trajectories, bomb scoring and control of the head slaved AOI. This system will hereafter be referred to by the image generation and display technology it utilizes (i.e., TMB/Dome Projection).

c. <u>Simulator for Air-to-Air Combat (SAAC/F-4E No. 18 Simulator)</u>

The SAAC was developed for TAC for training and the development of new air combat tactics. The device is a two-cockpit one-on-one aerial combat simulator located at Luke AFB, Arizona. The cockpits are configured as hardwing F-4Es and are mounted on six DOF synergistic motion systems (Figure I-5). Additional kinesthetic cues are provided by a buffet system, a G-seat, and a G-suit. The F-4E No. 18 simulator was previously modified to include a limited visual air-to-ground weapons delivery simulation capability. It is collocated with the SAAC. Image generation is by TMB technique. The configuration designed for this project utilized the image generation from F-4E No. 18's model board and was displayed in the SAAC. The model board was modified to include three-dimensional models of conventional gunnery ranges and a photomosaic airfield/industrial complex (Figure I-6). The visual display system is a mosaic of inline infinity optical windows, similar to ASUPT, but consisting of eight windows utilizing 27-inch CRTs. The SAAC has a unique dual raster scanning system. The large fixed raster presented the sky and earth imagery. The background terrain was a checkerboard displayed in four shades of gray. The other raster was variable in size and position and was used to display an AOI in a 40° X 40° format. Dynamic control of the AOI was target fixed. The optical probe was slaved to continuously look at the target as the area of interest. This system will hereafter be referred to by the image generation and display technology it utilizes (i.e., TMB/Optical Mosaic).

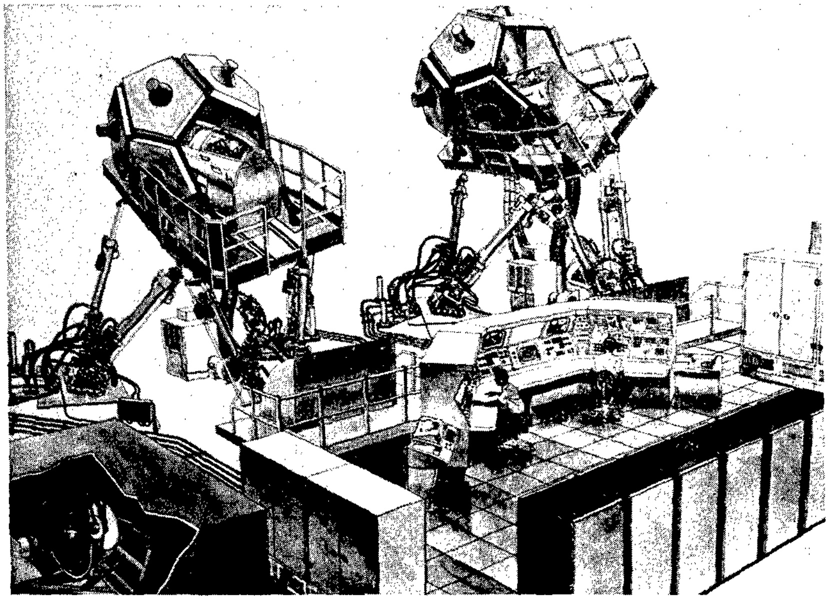


FIGURE I-5 SAAC

FIGURE I-6 F-4E No 18 MODIFIED MODEL BOARD

d. Device 2B35 (Visual System)

The 2B35 device is located at Chase Naval Air Station, Beeville, Texas. It is being utilized by the Chief of Naval Air Training in the Navy Undergraduate Pilot Training Program. This visual system consists of a CIG image generator, a display subsystem, and peripheral equipment interfacing with Device 2F90, TA-4J Operational Flight Trainer (Figure I-7). The CIG technology is similar to that used by ASUPT with the addition of a color image. Once the image is generated, it is converted to color television video and then projected by light valve projectors onto a wide-angle ($\pm$ 105° horizontal X $\pm$ 30° vertical), floor-mounted flat screens display situated around the cockpit station. This system will hereafter be referred to as CIG/Light Valve Projection (Screen).

5. MANAGEMENT

a. Air Force Systems Command

(1) ASD/SD24F

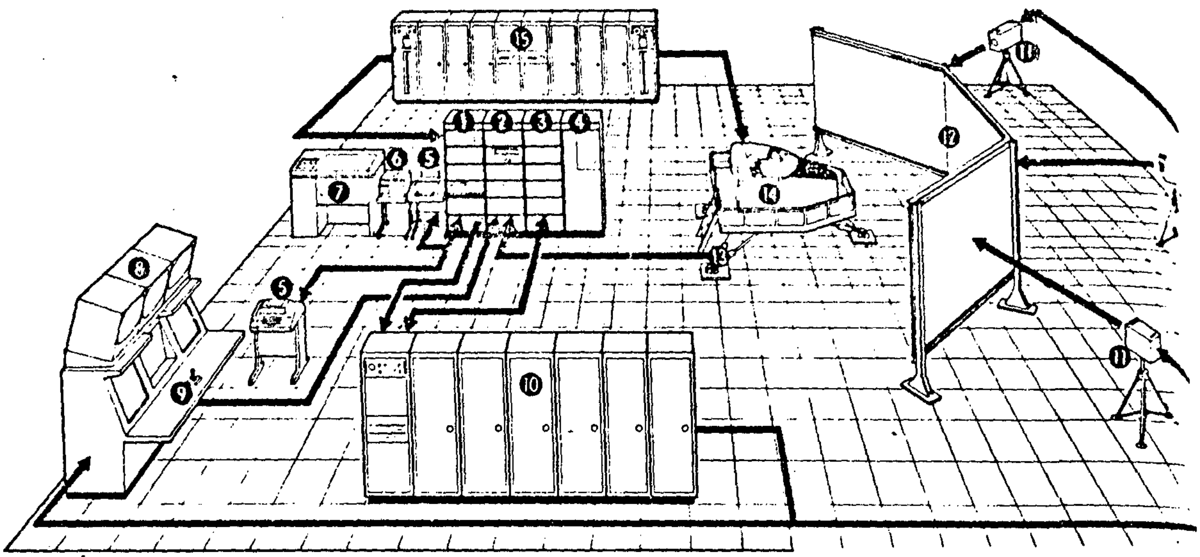
The Aeronautical Systems Division, Simulator System Program Office, Fighter Division (SD24F) located at Wright-Patterson AFB, Ohio had overall program management responsibilities. These responsibilities included the following: management of Phase I Engineering Evaluations; participation in Phase II Pilot Evaluations; management of the preparation of the Phase III Final Report.

(2) ASD/ENETV

The Deputy of Engineering, Directorate of Equipment Engineering, Visual and Electro-Optical Branch was responsible for developing and accomplishing the Phase I Technical Evaluation. Additionally, ENETV provided an AFSC pilot for the Phase II operational evaluation.

b. Tactical Air Command

Hq TAC, Directorate of Fighter/Reconnaissance Requirements, Simulator Division (DRFS), Langley AFB, Virginia, maintained overall management responsibility for project activities within TAC. Development and conduct of the Phase II Pilot Evaluations was assigned to the Directorate of Operational Plans and Support, Instructional Systems Division (DOXS). The United States Air



General Purpose Computer, includes:
Central Processor Unit (1)
Disk Drive, Controller and Calibration Panel (2)
Extension Cabinet (3)
Mag Tape Transport (4)
Teletypewriters (5)
Card Reader (6)
Line Printer (7)

8. TV Monitor Assembly

9. Joystick Assembly

10. Special Purpose Computer Image Generator

11. Light Valve Projector

12. Display Assembly

13. Motion Platform Assembly

14. 2F90 Cockpit

Figure I-9 2B35 System

Force Tactical Air Warfare Center, Directorate of Full Mission Simulators (USAFTAWC/TES), assigned personnel to participate, assist, and manage TAC activities as directed by TAC/DRFS.

6. METHOD OF EVALUATION

The evaluation was a three-phased effort consisting of a technical evaluation (Phase I), an operational evaluation (Phase II), and a reporting phase (Phase III). Limitations encountered during Phase II were provided to the equipment engineers for discussion and identification of possible technical solutions.

a. Phase I Technical Evaluation

Phase I was an engineering evaluation conducted to measure the performance of each system. The evaluations were a series of instrumented tests designed to measure the system's static and dynamic capability. The technical measurements selected (reference Section II, paragraph 3) were those considered to be most appropriate in terms of individual system characteristics. Phase I results are contained in Section II. Specific test methods and data obtained are contained in Volume 2.

b. Phase II Operational Evaluation

The Phase II operational evaluation consisted of six qualified fighter pilots flying approximately ten sorties, each sortie increasing in task complexity, in each of the primary devices.

System capabilities and limitations were identified utilizing the real-world performance of a specific task as the standard. If deviation from this normal task performance was observed, a determination was made as to why and to what extent performance was altered, and in what manner the limitation was overcome. Mission scenarios and sample questionnaires are contained in Volume 2.

The data collected consisted of mission recordings of inflight comments and questionnaires on which all tasks and significant areas were rated. Numerical ratings were documented with supporting narrative comments.

c. Phase III Reporting

Phase III was the reporting phase. This phase consisted of the formal analysis of Phase I and II strengths and limitations, analysis of the engineering responses to the limitations, and the subsequent development of Required/Optimized System features. Section III of this report contains the analysis of quantitative data, assessment of limitations and anomalies, and significant strengths to arrive at a required/optimum system representing each combination of technologies and an assessment of technical risk to achieve the systems. Section IV contains a comparative analysis of optimized features (including a hypothetically developed CIG/Dome Projection System) was then accomplished considering the simulator features required to allow performance of specific flying tasks and the associated technical risk. The conclusions and recommendations of this analysis are contained in Section V and VI respectively, and are summarized below.

7. SUMMARY OF CONCLUSIONS

The conclusions listed below are based on two predominant criteria; best operational utility, and lowest affordable technical risk. These criteria are consistent with the purpose of this project.

a. State of the Art (SOA)

Visual air-to-ground weapons delivery simulation was demonstrated with SOA technologies. Operational utility of the simulations varied between technologies (reference Section III).

b. CIG/Optical Mosaic

A system utilizing CIG and an optical mosaic provided satisfactory visual cues, had a sufficient FOV, and possessed the flexibility essential for air-to-ground task accomplishment. Performance of most controlled range weapons deliveries and many tactical weapons delivery tasks could be accomplished with little or no alteration when compared to actual inflight task performance. It is estimated, however, that with the addition of the following features, system limitations or anomalies will be alleviated and thus the CIG/Optical Mosaic technology can be optimized:

(1) Low Risk

(a) A significant increase in edge processing capability to provide enriched environments.

(b) The reduction of image distortions caused by optical window seams.

(2) Medium Risk (Engineering Development)

(a) An increase in the resolution capability of the display system.

(b) Generation and display of more realistic cloud ceiling conditions (reference Section III, paragraph 1b(2)(a)4, p. III-17).

(3) High Risk* (Research and Development)

(a) The generation and display of surface texture with a minimal use of edges.

(b) The display of color imagery.

c. TMB/Dome Projection

A system utilizing these technologies has marginal operational utility for air-to-ground weaponry task performance. Significant improvements in image generation and display technologies are required before this approach can be successfully employed. Careful analysis of potential systems capabilities must be accomplished to assess the long term benefits before research and development resources are allocated to improving this approach.

d. TMB/Optical Mosaic

A system utilizing these technologies can not be used to satisfactorily perform air-to-ground weaponry tasks due to formative technical limitations and high risk associated with engineering corrections. TMB/Optical Mosaic system technologies should not be pursued for application to the air-to-ground role. Further evaluation of this approach is recommended only if significant technical advancements associated with these technologies are achieved as a result of independent research.

*NOTE: Inclusion of R/D Items are not required to provide a usable system. These are included to optimize the CIG/Optical Mosaic Approach. Ground texturing algorithms should be included in this system when perfected.

e. CIG/Dome Projection

A hypothetical system utilizing CIG and Dome Projection technologies was considered. Its features represent various optimized features included from the other systems evaluated during Phase II. This system can potentially allow the performance of air-to-ground weapons delivery tasks. In addition, this approach has the potential to simultaneously display high resolution, air-to-air targets and high resolution ground imagery for both air-to-air and air-to-ground task performance. The system at this time cannot be considered a near term solution to the air-to-ground weapons delivery problem due primarily to the lack of a sufficiently large AOI capability or display of ground imagery throughout the entire FOV. The following features will require research and/or engineering development before the potential of this system can be realized:

(1) A high resolution, wide angle projection system capable of providing the large AOI or full FOV containing the ground imagery necessary for the accomplishment of air-to-ground tasks. Detailed ground imagery throughout the full FOV should be considered as the ultimate design goal.

(2) Improved edge processing capability, addition of surface texture, and correct simulation of ceiling conditions as developed for the CIG/Optical Mosaic system.

(3) The display of a low detail dynamic background in the event that full FOV imagery can not be achieved.

(4) The simultaneous display of air-to-air and air-to-ground targets in a high-gain, sperical dome of optimum size.

(5) The display of color imagery.

8. RECOMMENDATIONS

As a result of this project, the following actions are recommended:

a. Initiate a program that will provide a production prototype CIG/Optical Mosaic System in a cost-effective manner. The system should have expanded capability to fulfill as many A-10 operational requirements as possible. The prototype should incorporate low risk improvements with medium and high risk improvements as design goals (reference Section V, paragraph 1.b for details). As results of medium and high risk development efforts are achieved, they should be evaluated by program management personnel for compatibility with program milestones and incorporated into the system. The production prototype should include the following descriptive characteristics:

(1) Two-cockpit configuration with a shared CIG system.

(2) Enriched ground environment.

(3) Multiple moving models.

(4) Monochrome display.

(5) Special effects (reference Section IV, Table IV-1 for listing).

b. Pursue studies and/or research and development efforts in the following areas:

(1) Initiate an effort with sufficient priority to evaluate the engineering feasibility of developing a prototype CIG/Dome Projection System (with enriched ground environment throughout the FOV or optimum size AOI). Sufficiently high priority should be placed on this effort because of its potential to permit simultaneous performance of air-to-ground and air-to-air tasks (reference Section V, paragraph 1.3 and Section IV, paragraph 1 for detail and discussion).

(2) Ground Texturing in CIG environments.

(3) Optical window optimized for color transmission.

(4) Definition of the optimum size of an AOI which would allow unaltered task performance.

SECTION II

EVALUATION PROCESS

1. INTRODUCTION

The systems described below were selected as the most current SOA systems which represented advanced visual technology applicable to air-to-ground simulation. Among these characteristics which were considered pertinent to evaluate were the distinct differences in both image generation and display technologies. The devices as they are described below reflect the Project 2235 configuration. Available simulator features that were not used during the operational evaluation have been omitted from the system descriptions.

2. DETAILED SYSTEMS ENGINEERING DESCRIPTIONS

a. CIG/Optical Mosaic System

The CIG/Optical Mosaic System evaluated consisted of two aircraft cockpits, each having a six DOF synergistic motion base, and a G-seat with an active seat belt for producing onset and sustained motion cues. Surrounding each cockpit were seven CRTs with infinity optics providing a wide FOV visual display. The visual scene was produced by a CIG system which provided a two-dimensional (2-D) image in perspective of a digital environmental model stored in computer memory. Advanced instructional features were provided by in-cockpit, conventional, and advanced instructor/operator stations.

(1) Visual Generation

CIG systems produces a video signal through the use of general and special purpose digital computers.

Visual scenes are generated in the following manner. Each feature to be displayed in the environment is approximated by a set of planar faces. Each face is defined by a set of edges and a gray shade. Basically, the three-dimensional (3-D) coordinates of each of the two vertices defining each line segment, or edge, face, grayshade, and associated information are stored in computer memory (See Figure II-1).

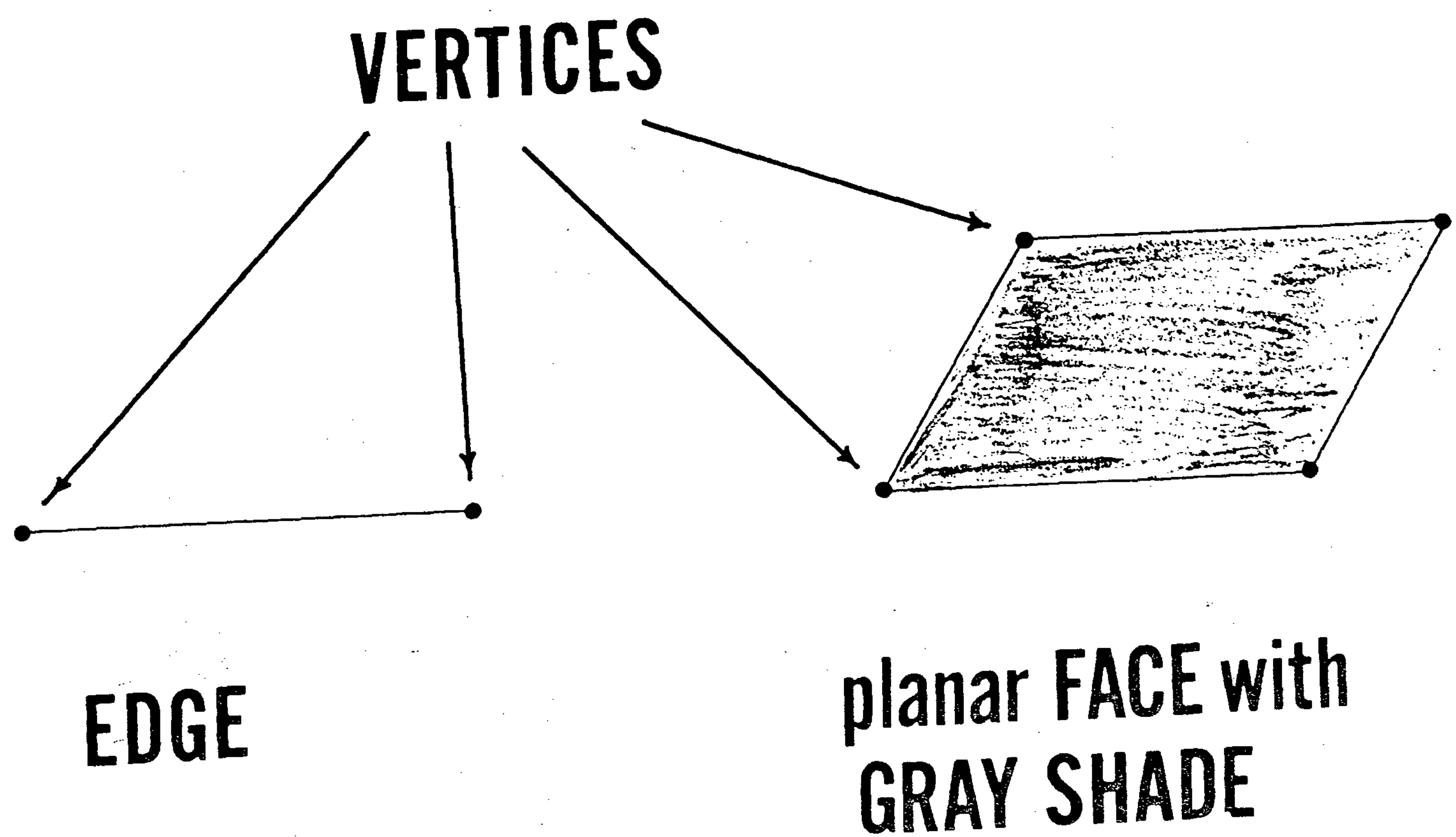


Figure II - 1 CIG Edge and Face

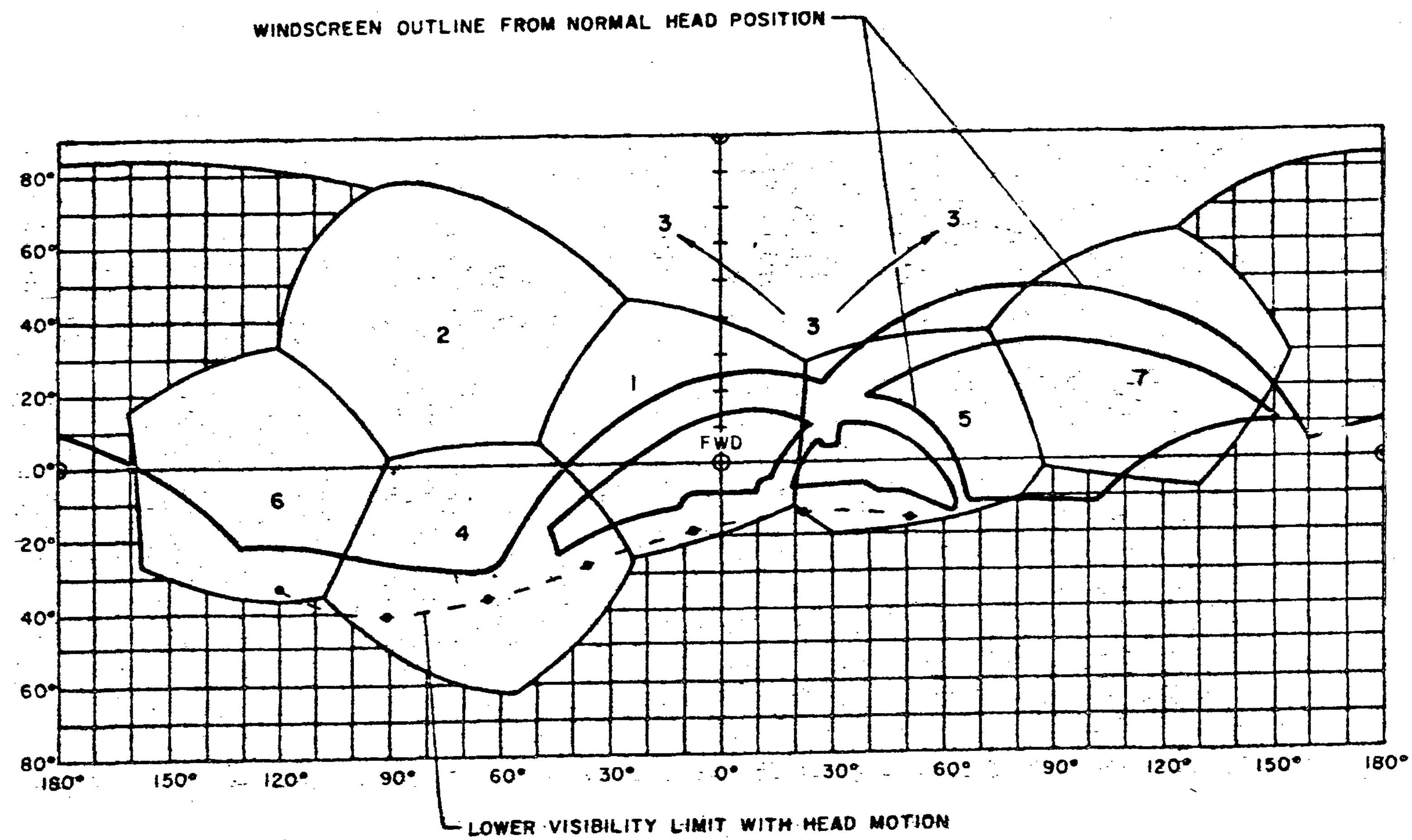


FIGURE II-2 ASUPT WINDOW NUMBERING SYSTEM

As the simulated aircraft moves through the environment, only the edge data in the immediate vicinity is retrieved from mass storage for processing. This eliminates processing data for features too distant to be discernible. Visible edges of the 3-D model environment are mathematically transformed into numerical data representing the geometric projection of the seven-channel, 3-D model onto the 2-D viewing windows.

This 2-D seven-channel math model is then converted into a CRT raster line format where each raster line element is assigned a digital brightness. A high-speed, digital-to-analog converter then transforms this information into a video signal which is then displayed on the seven CRTs.

The visual environmental data bases are stored on magnetic tapes or disc packs. The environment to be viewed is loaded into accessible mass storage (dual fixed head disks) by a media conversion.

Each environment is limited to a square area 1250 nautical miles on a side and can contain, at most, 600,000 edges. Computational processing limits the system to display a 2000 edges with an additional 500-edge overflow buffer at any one point in time.

(2) Visual Display

The visual display consisted of seven pentagonal display windows (pancake windows) mosaicked around each of the cockpits providing a FOV of approximately $\pm$ 150° horizontally and + 110° -40° vertically (Figure II-2). The 36 inch CRTs used a high efficiency phosphor to obtain the required display brightness. Images produced by the CRTs were viewed through in-line optics which collimate the light rays to provide a two-dimensional infinity image.

(3) Computers

The CIG/Optical Mosaic System evaluated was served by three Systems Engineering Laboratory (SEL) Systems 86 general purpose computers. They were designed for the high-speed operations required for a real-time system. One SEL 86 was used to drive the simulator aircraft. The CIG system utilized two SEL 86s and a General Electric (GE) Special Purpose Computer. The two SEL computers performed the bookkeeping and numerical calculations for processing the 3-D math model of the visual environment in the vicinity of the simulator aircraft. The GE computer was a hardwired device and performed the high-speed operations necessary to convert the 3-D math model to a raster format for generating a 2-D perspective video.

(4) Advanced Instructional Features

The following features were available to the operator.

(a) Environmental Conditions

The following environmental conditions were adjustable from the operator station:

Visibility	Turbulence
Ceiling	Runway Condition (Wet/Icy)
Wind Velocity & Direction	Day/Dusk/Night Conditions
Temperature	

(b) Freeze

Activation of the freeze mode by the operator immediately froze the visual scene, instruments, and motion system.

(c) Initialization

This feature allowed the simulator to be instantly positioned to several different preset conditions. This set all flight parameters, environmental conditions, and geographic coordinates. An additional capability allowed the pilot or console operator to store a condition during flight for later reinitialization.

(d) Graphic Displays

Two programmable graphic displays were available to capture real-time aircraft parameters in any desired format and to portray dynamic movement in 2-D or 3-D planes.

(e) Hardcopy Printouts

Hardcopy reproductions of the alphanumeric monitor displays were available.

(5) Kinesthetic Simulation

Onset motion cues were provided by a six DOF synergistic motion platform driven by six hydraulic actuators with 60-inches of travel. Each platform also had six passive actuators for safety purposes. The motion system possessed a programmable buffet capability.

Sustained motion cues were provided by means of a G-seat and lap belt. Thirty-one independent pneumatically driven cells were contained in the lefthand seat of each cockpit. The seat pan contained 16 cells; the back rest, nine cells; and each of the thigh panels contained three cells. Additional cues were provided by an active lap belt.

(6) Project 2235 Modification[1]

Significant software and hardware modifications were necessary to provide the expansion of system capabilities. Extensive algorithm development and implementation of software programs was required to generate weapons trajectories, ordnance weapons effects, moving model paths, moving model image size control, and weapons delivery scoring. A new visual data base was designed to provide an appropriate environment in which to perform air-to-ground missions. Two CRT graphics displays were programmed to present aircraft delivery parameters (dynamic and at release) and weapons delivery scoring. To accommodate the additional software, a moving head disk drive and additional computer core memory were purchased and installed. In addition, an optical gunsight (CA 503) was obtained and modified to fit one of the simulator cockpits.

Figures II-3 through II-8 were taken of a console black-and-white TV monitor (slaved to the forward channel of the display system), present a 75° horizontal by 55° vertical FOV, and depict some of the features in the environment.

[1]Information contained in this section is extracted from "Air-to-Surface Weapons Delivery Simulation With a Computer-Image Generation System, Modeling and Simulation", 1976.

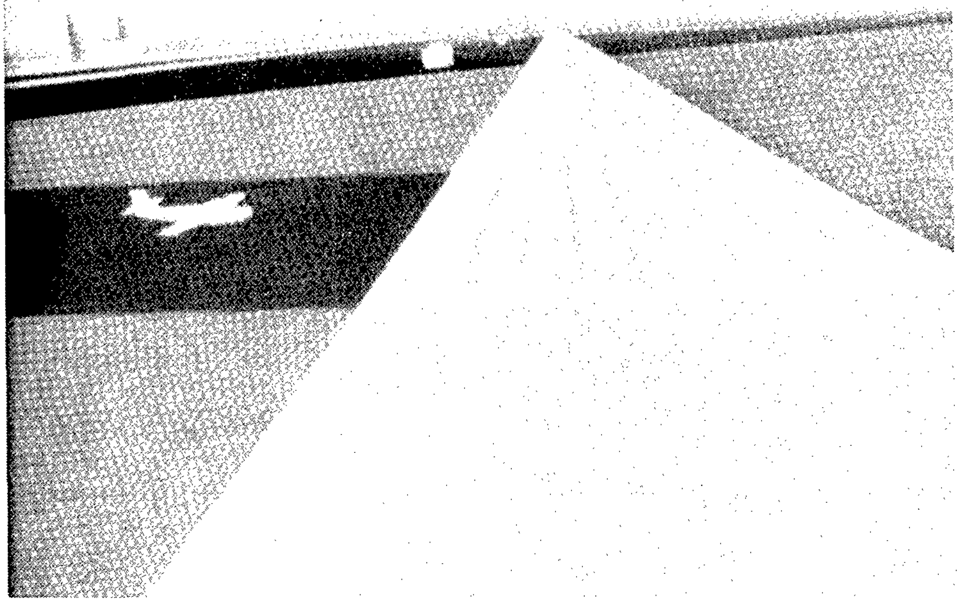


Figure II - 3 Airfield

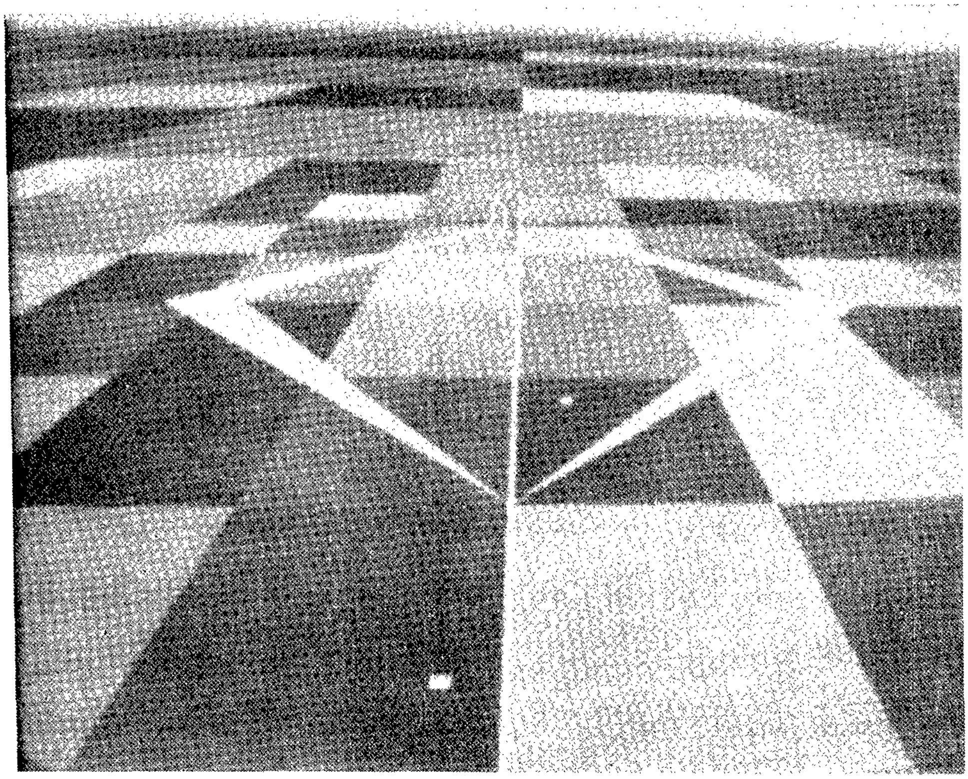


Figure II - 4 Conventional Range

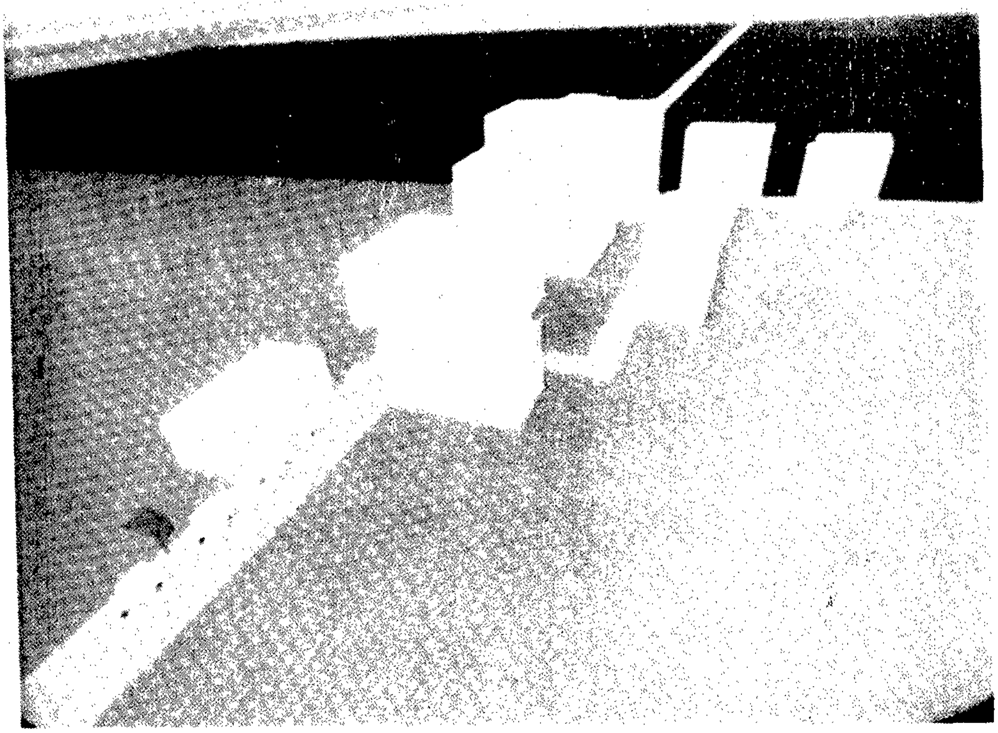


Figure II - 5 Truck Convoy

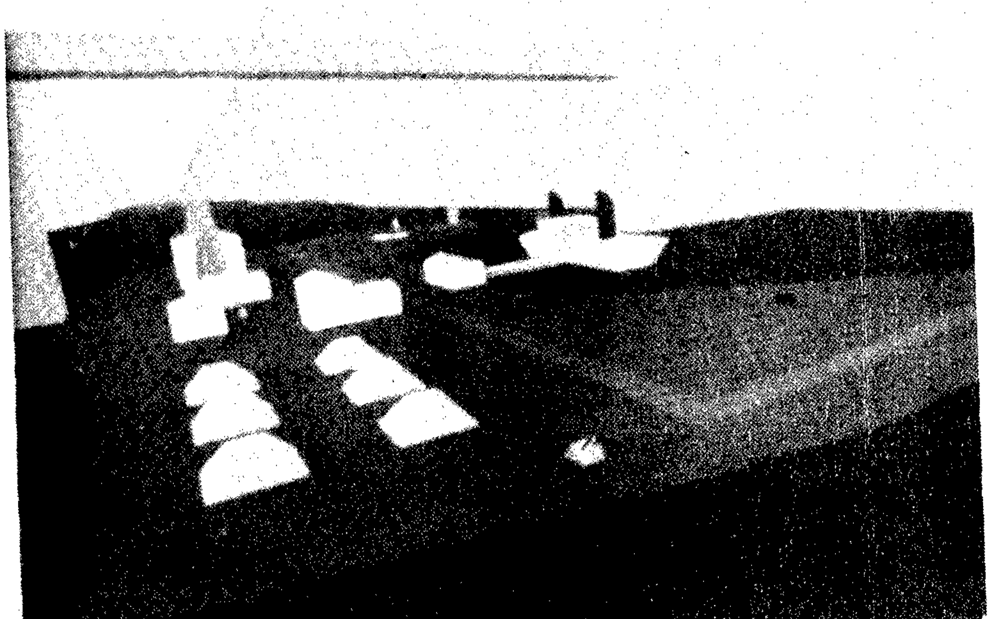


Figure II - 6 Factory Complex

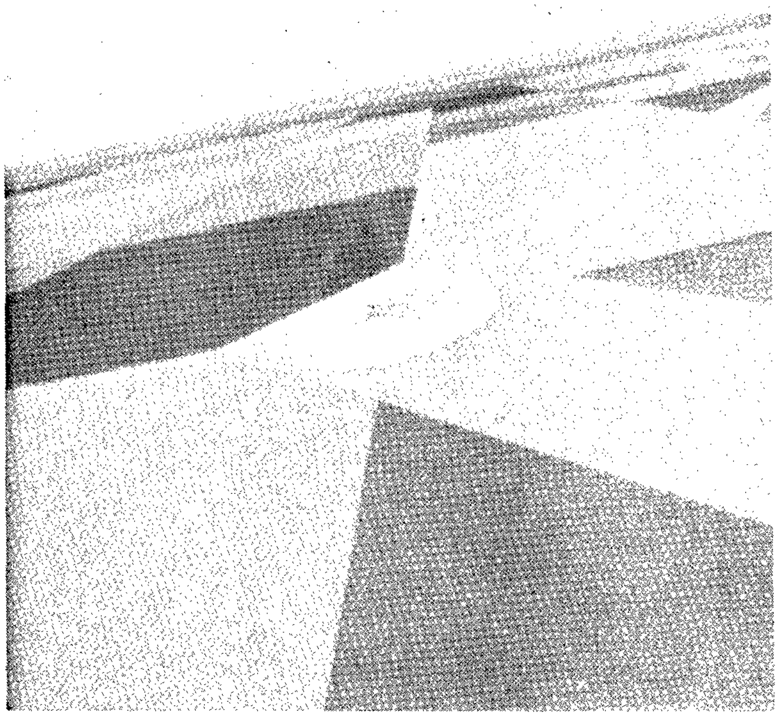


Figure II - 7 Weapons Impact

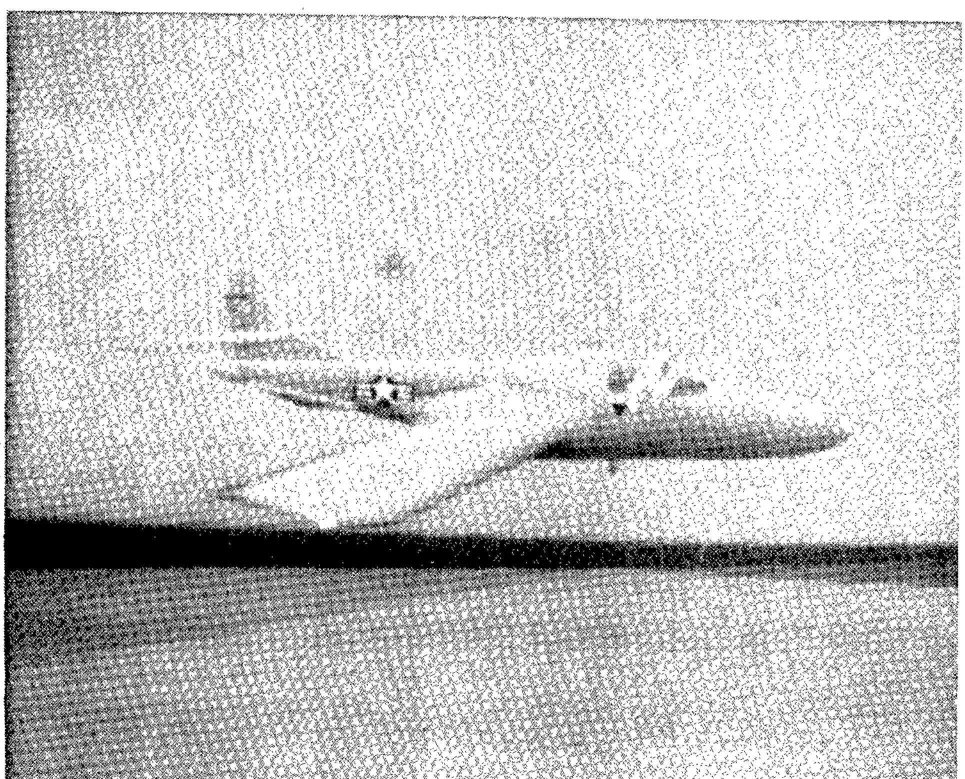
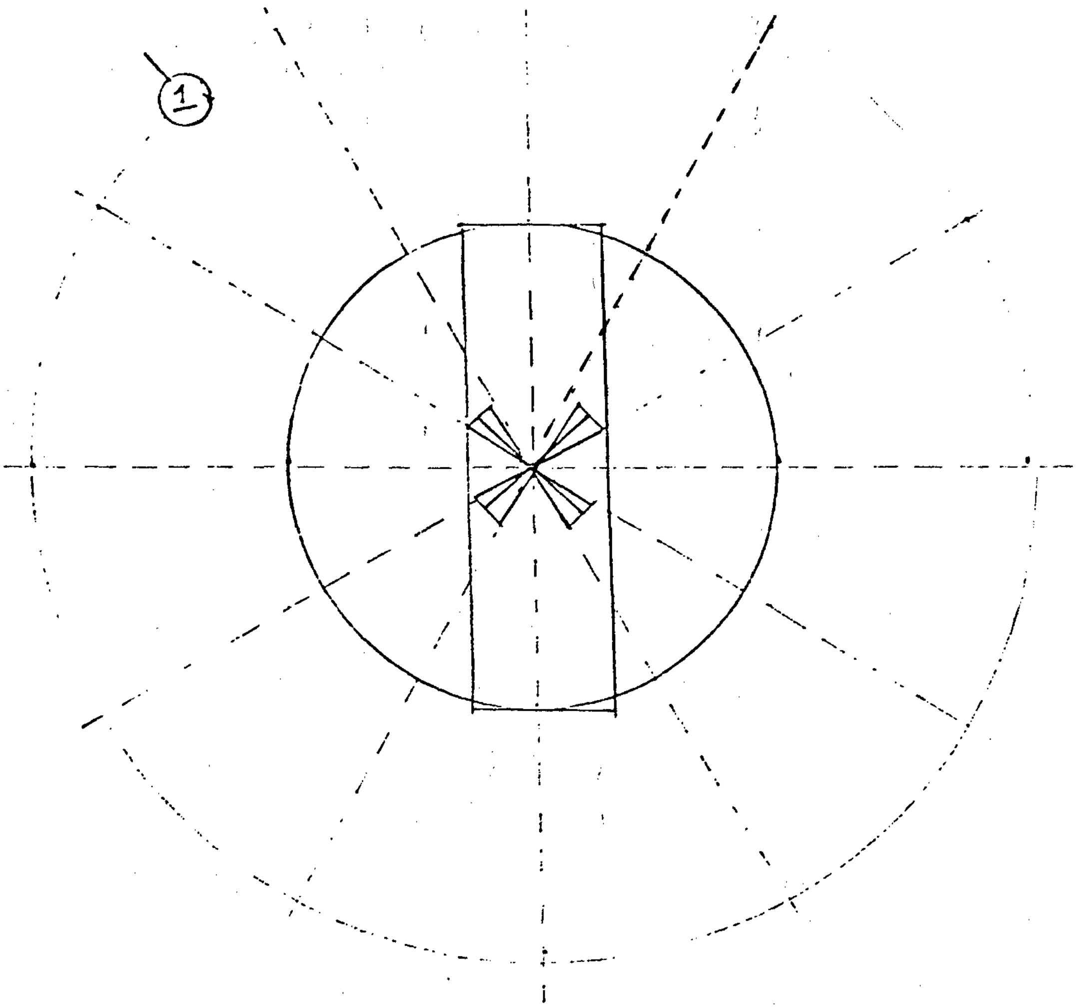


Figure II - 8 Formation Aircraft



TARGET NO. 1

Pass	Heading	Altitude	Kias	G-load	Dive Angle	Wind dir/spd	Dist
1	300	800	250	1.3	25	270/10	300
.							
.							
.							
10							

FIGURE II-9 - DYNAMIC DELIVERY DISPLAY

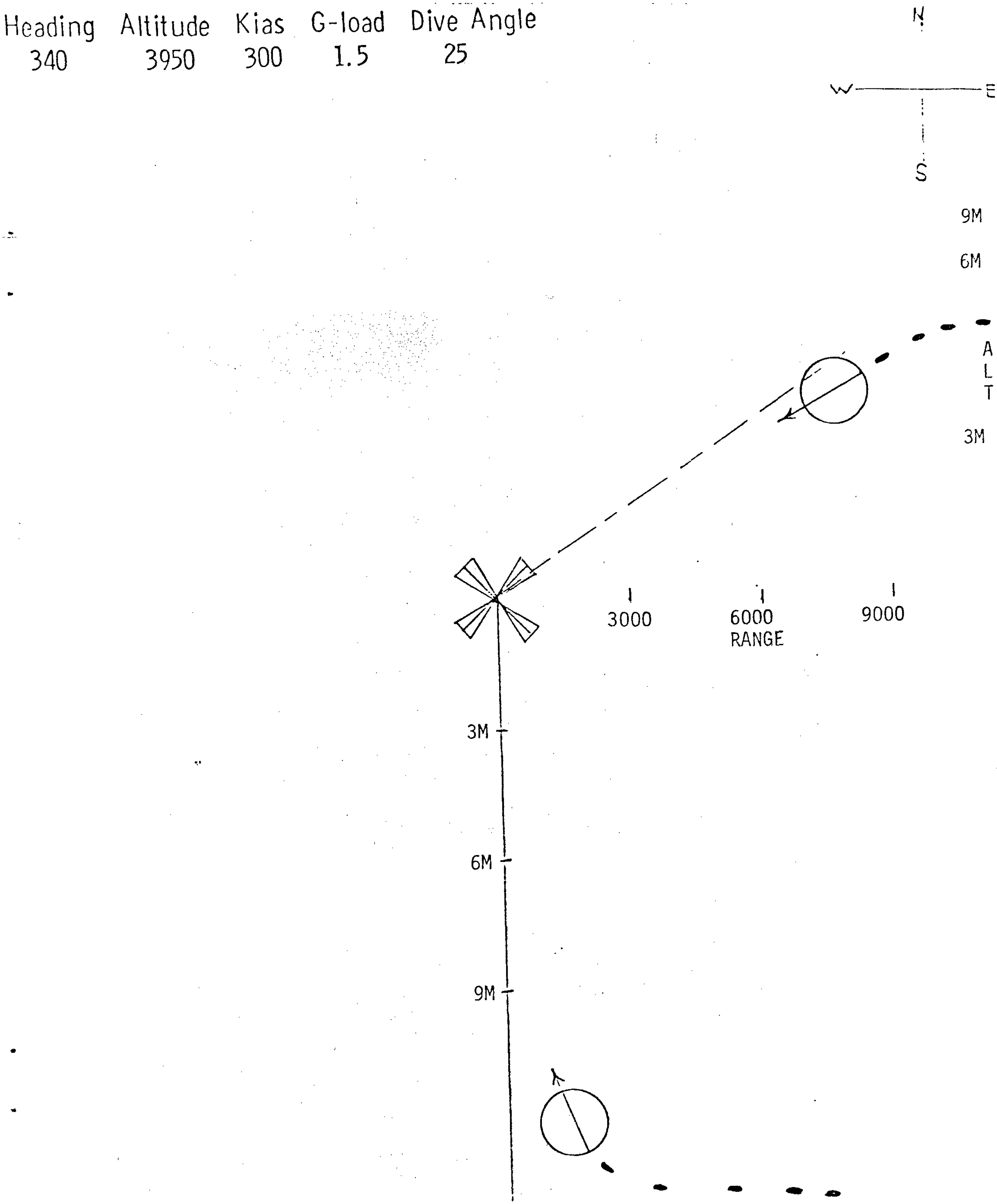


FIGURE II-10 - WEAPONS/TARGET IMPACT DISPLAY

The environmental gaming area consisted of a square area 36 nautical miles on a side and included a random surface pattern, an airfield, a gunnery range, and two tactical complexes.

The airfield (See Figure II-3) was composed of a 12,000-foot runway with three-dimensional features.

The conventional gunnery range was a baseball diamond pattern as shown in Figure II-4 and consisted of two bomb circles, two skip bomb targets, two strafe targets, associated range buildings, range towers, and trucks in the bomb circles.

Two graphics displays were programmed to provide scoring and monitoring of ordnance delivery. The aircraft delivery parameter display provided a dynamic side and top view of the aircraft relative to the selected target, with a real time digital readout of heading, altitude, airspeed, dive angle, and G-load (Figure II-9). This display also presented strafe scoring as a percentage of projectiles fired that passed through the target and a foul indication when appropriate. The target/impact display was a top down view of the target center with radial lines at the o'clock positions and concentric circles of 150 and 300 foot radius (Figure II-10). The impacts were shown relative to the target as circles with pass number in the center. The aircraft delivery parameters at time of release for up to ten passes were printed at the bottom of the display along with the distance of the hit from target center. Weapon delivery information was available on hard copy printout.

One of the tactical ranges consisted of two small towns approximately four miles apart, including a SAM site. As visible in Figure II-5, a convoy of trucks was located in one of the towns. The other tactical area was located in a river valley between two mountain ranges spanned by a pair of bridges as partially shown in Figure II-6. In the vicinity of one bridge was an island containing a munitions factory. Several features in this tactical area changed locations, depending on the day, dusk, or night environmental selection.

Visual ground impacts were displayed for both strafe and bomb, and when a three-dimensional feature was hit, it was momentarily deleted from the display scene. These features may be observed in Figure II-7.

With both cockpits flying independently, each could view the other as the moving model. Formation mutual support and forward air control tasks were performed in this configuration in one area of the environment. An image size control program was implemented to introduce a dead range for which the moving model image size remained constant. This was done in an attempt to alleviate the resolution problem occuring with the aircraft image of ranges beyond 2,500 feet. Figure II-8 shows one of the moving models which was used for formation flight. A more simplistic model was used for the lead and forward air control aircraft. Target marking by a forward air controller was accomplished with a simulated ground smoke marking near the convoy which was selectable at the operator station.

Ground fire was simulated by muzzle flashes of the anti-aircraft artillery and tanks. Aerial flak bursts also accompanied the anti-aircraft artillery in the vicinity of the munitions complex. A missile could be repeatedly launched from the SAM site and would track the aircraft. The missile could be evaded if proper evasive tactics were performed in response to the missile's trajectory.

A moving tank could be selected and moved among the towns, SAM site, and highway between the two towns. When attacked and experiencing a near miss, the tank left the road randomly changing speed and direction to confuse the attacker. When attacked and hit, the tank would disappear. Only one moving model (SAM, tank, other aircraft) could be selected at any one time.

b. TMB/Dome Projection System

The TMB/Dome Projection System evaluated consisted of a single fighter cockpit mounted on a five DOF large amplitude motion system. A 20 foot spherical screen which surrounded the cockpit was used to display the imagery from a dual projector system. The visual AOI was generated from a TMB and complimented by background imagery provided by a sky/earth projector. A G-suit was used to provide additional onset and sustained G-cues.

(1) Visual Generation

The terrain image in this device was generated from a camera/probe system that was mounted on a gantry and traversed a large 3-D model. The gantry and probe movements were correlated with the aircraft flight path and attitude. During the head slaved portion of the evaluation, the position of the AOI was computed as the geometric sum of the pilots head position and aircraft orientation.

The TV camera image was then projected by CRT target projector onto the surface of the spherical display screen.

The terrain models were 15 feet high and 47 feet long and include scale models of urban and rural terrain with an airport complex containing strobe and approach lights, and urban lighting schemes. One model represented an area 3 x 11 nautical miles (1500:1 scale) and the other 11 x 36 nautical miles (5000:1). The system was capable of simulating haze and overcast ceiling. The area viewed by the optical probe was continuous in heading and roll but limited in pitch to +24° to -47° and was displayed as a 60° diagonal AOI (48° wide by 36° high).

A second method of producing visual images was through the use of the Raster Graphics System (RGS). This system could generate a pre-programmed image consisting of up to 32 flat, three or four sided faces, and was configured to allow future expansion on a modular basis. Software for the RGS system included a program to display a truck and a runway complex.

The RGS runway complex was demonstrated during Project 2235. Due to time and technical constraints, a satisfactory demonstration of the movable truck was not accomplished.

(2) Visual Display

The visual display system consisted of a 20 foot diameter, spherical shaped screen, mounted on the cockpit gimbal system, which moved with the cockpit, and two projectors. One monochrome projector, mounted above and behind the pilot, projected the image of a target, which could be either another aircraft (not used during Project 2235) or a ground based target or terrain image (used for this evaluation). The other projector, mounted above and slightly behind the target projector, known as the sky/earch projector, projected a clear blue sky with occasional clouds, a featureless brown earch, and a continuous, well-defined mountainous horizon on the inner surface of the spherical display screen.

The pilot's seat was located so that the pilot's eyes were in the exact center of the spherical screen to avoid distortion of his view of the projected images. This meant, however, that the target projector and sky/earth projector could not be located at the center of the spherical screen. Therefore, the projector contained design features to correct for the resultant distortion: the target projector had a focus servo which moved the CRT, with respect to the lens, a proper distance to compensate for the varying throw distance or focal length from the lens to the surface of the screen; the target projector also had keystone correction provisions in its raster control circuitry to compensate for the varying angle at which the projected image beam impinged on the surface of the screen; the sky/earth projector had a mechanism inside the two hemispherical transparencies which positioned the point-light source of the sky lamp (and the earth lamp, mounted on a common vertical shaft) to proper X, Y, and Z coordinates within the transparency, so that the projected horizon position would be correctly located and without distortion.

The FOV of this device was ± 133° horizontal and 108° vertical and was limited primarily by cockpit gimballing on the motion system and by the projection system location and configuration.

The terrain image could be displayed to the pilot in three ways. The first was to fix the AOI to the x-axis of the aircraft. The terrain image within the AOI would then move solely as a function of the orientation of the aircraft. A second method was to fix the AOI to a specific predetermined target. With this method the visual probe pointed to the target at all times and the image was displayed on the dome in the properly oriented position. The third method was to position the probe over the terrain based on the pilot's viewing angle and the location of aircraft. The image displayed was therefore a function of aircraft location, aircraft attitude, and the pilot's head position.

The computer also calculated and commanded the proper horizon position (above or below the pilot's forward line-of-sight) and horizon attitude (level or tilted) from the sky/earth projector. A jagged horizon, representing mountainous terrain, provided directional cues to the pilot.

The head-slaved visual system for this project required the ability to accurately monitor the pilot's head position. This had to be done in a manner which was unobtrusive to the pilot so as not to affect the pilot's normal task performance.

The hardware used in this experiment was a SOA helmet sight system. Sensor surveying units were rigidly fixed to the cockpit and aimed in the direction of the pilot's head. These units emitted fan-like beams of infrared light rotating at a constant velocity. The infrared beams swept over a reference photo sensor and two pairs of helmet mounted sensors, one on each side of the helmet. The time intervals between the pulses from the helmet photo sensors and the reference sensor were a measure of the pilot's head orientation relative to the body axis of the aircraft. The outputs of the photo sensors were transmitted to the helmet sight computer and a special purpose digital computer where the angular computations were performed and converted into azimuth and elevation information.

(3) Computers

The TMB/Dome Projection System evaluated contained two computers: a relatively small interface computer, identified as the EAI PACER system, which drove the simulator and stored and processed the computer programs (software) that controlled, checked-out and diagnosed the various simulator subsystems; a much larger hybrid computer, consisting of the EAI 8400 digital/7800 analog/8930 linkage modules, and items of peripheral equipment. During simulator operation, this computer stored and processed the airplane programs (i.e., equations of motions for the aircraft being simulated).

(4) Operator's Station

(a) Monitor & Control Console

The monitor and control console provided a central location for electrical and electronics subsystems hardware required for operation of the simulator's numerous servo controllers and its video-optical equipment items, and also served as the central point for the computer interface subsystem to be connected with the simulator visual display and motion subsystems.

The console consisted of five major sections: Section 1 contained power amplifiers and power supplies; Section 2 contained test, interface, and servo electronics for the visual display system; Section 3 contained motion system and cockpit electronics; Section 4 contained the video system electronics; and Section 5 was the operator's control station.

(b) Instructor's Station

A small instructor's console was established with a color monitor that repeated the AOI and an over the shoulder monitor used to view the relationship of the pilot, AOI, and centerline. A program was written to store the aircraft position, velocities, and accelerations at weapon release and compute the ordnance impact point with respect to the target. This information was displayed on an informational television screen. This program also allowed the data to be dumped to the line printer after each weapon delivery for a permanent record of the pilot's releases.

(5) Kinesthetic Simulation

The motion system consists of a 30 foot long horizontal beam, which was gimballed and driven by hydraulic actuators at the rear of the beam to provide $\pm$ 10 feet of vertical motion and $\pm$ 10 feet of lateral motion to the cockpit. An additional structure, the cockpit gimbal system, was mounted on the forward end of the beam, and provided three-dimensional rotation ($\pm$ 25 degrees in pitch, yaw and roll motion) to the cockpit. Safety features of the motion system included a hydraulic counterbalance in beam vertical motion, remotely operated lockout devices for cockpit pitch and roll actuators, and a system of limit switches, combined with internal snubbers in all of the cockpit and beam actuators to provide a controlled and limited deceleration at the end of each actuator's stroke.

(6) Project 2235 Modifications

The data package for Project 2235 was a basic A-10 aircraft used in a previous simulation. However, to perform the take-off and landing requirements, data was added for the landing gear and flaps. To perform the weapons delivery requirement of the project, a digital computer program for weapon scoring was obtained from NTEC and modified for this system. A gunsight was installed in the cockpit.

The headslaved visual system was felt to be a major requirement of the project and also received the most attention. A SOA infrared helmet sight system was procured and installed in the cockpit.

Software to drive the visual probe and target projectors was then developed. These routines included data scaling, conversions, axes transformations, feedback signals, and lead compensation for the probe.

A second visual program was developed to provide a target slaved visual presentation. Software included a routine to compute the vector between the pilot's eyes and the target and positioned the probe to look along that vector as well as respond to the aircraft's orientation. A second routine calculated where this vector would intersect the spherical projection surface and command the target projector to display the visual image at that point.

Moving targets on the RGS were also programmed and checked out along with development of a forward air controller (FAC), however, these were not used during the pilot evaluation.

Further refinements in the weapon delivery requirements were to provide scoring for a number of different targets, which required locating those targets on both the 1500:1 scale board and the 5000:1 scale board and recording their x, y, z coordinates for later use in scoring.

A small instructor's console was established with a color monitor that repeated the AOI and an over the shoulder monitor used to view the relationship of the pilot, AOI, and centerline. A program was written to store the aircraft position, velocities, and accelerations at weapon release and compute the ordnance impact point with respect to the target. This information was displayed on an informational television screen. This program also allowed the data to be dumped to the line printer after each weapon delivery for a permanent record of the pilot's releases. Other small modifications included a change to the probe to allow its full -47° down limit, the addition of a software limit which prevented the probe from descending below a pre-determined minimum altitude, and the development of different levels of night lighting by modification of the sky plate intensity.

c. TMB/Optical Mosaic System Overview

The TMB/Optical Mosaic System evaluated used one cockpit integrated with a terrain model subsystem. Surrounding the cockpit was eight CRTs with special infinity optics providing a wide FOV visual display. The cockpit included F-4E instrumentation (and flight characteristics), a six DOF motion platform, seat buffet, a G-seat, and a G-suit. The visual image seen by the pilot covered a $\pm$ 148° horizontal and + 150° -30° vertical FOV. Visual imagery included a sky, a horizon, a checkerboard ground terrain image, and a 40° by 40° AOI showing imagery taken from the associated TMB. The AOI was slaved to one of several predetermined positions on the TMB. In flight, the AOI migrated about the total simulator FOV as the aircraft's location and attitude changed with respect to the ground target.

(1) Visual Generation

The visual system simultaneously displayed two sources of imagery; the sythethic terrain generator (STG) which provided a checkerboard ground and clear sky background and the AOI image from the TMB. The model board gantry, linkage, and computer hardware were used for generation of AOI imagery. A new optical probe was added to the existing gantry together with a new monochrome television camera. The probe was limited in pitch to a maximum down-look angle of -50 degrees. The camera, of basic commercial design, was used with an experimental large format plumbicon image tube. The video signal from the camera was fed to the display electronics. Four (of 18) sections of the model board were replaced with a combination of a photo mosaic and physical models scaled at 4000:1. The remainder of the model was left at 1500:1. The new area added an airfield and industrial complex and two types of conventional gunnery ranges (one diamond and one rectangular). Each range included targets for strafe, skip bomb, and dive bomb. The airfield complexes and the industrial areas provided targets for tactical weapons deliveries.

(2) Visual Display

The optical display consisted of eight in-line infinity optics windows (pancake windows). The windows were mounted in the form of a dodecahedron and edge matched to provide continuous imagery generally limited only by cockpit/aircraft configuration (Figure II-11). The display information was input to the optics by special monochrome CRTs with a unique dual raster scanning system. The background raster, or large fixed raster, presented the STG imagery. This checkerboard terrain (in four shades of gray) was provided by an electronic analog generator. When used in the air-to-air combat mode, the other raster was variable in size and position and was used to present the opposing aircraft. When used in Project 2235's air-to-ground mode, the small raster's size was fixed (at 40° by 40°) to enable display of imagery generated from the TMB. The AOI (small raster) display of the terrain was capable of migration anywhere within the eight windows. In the air-to-air combat mode, the small raster aircraft was superimposed over the checkerboard (STG) background image. For use during air-to-ground operations, specialized circuitry was designed, built, and installed to the STG imagery. In effect, the blanking circuitry cut a hole in the STG background located behind the AOI image as it migrated about the total FOV. This enabled operation of the display with equivalent brightness levels for AOI and background imagery.

(3) Visual System Integration

All system timing, synchronization, and computation required for the integrated system was provided by the SAAC. Aero computation was performed by the SAAC Sigma Five computer complex (with three central processors, disk, magnetic tape, line printers, etc). The sigma computers also provided all necessary data required for location of the AOI within the FOV, and for positioning the gantry/probe system. Digital signals from the SAAC computers were transmitted to the input bus of the F-4E No. 18 GP-4 computer, which in turn, control the gantry and probe. SAAC video synchronization signals were provided to the camera. The integrated SAAC/F-4E No. 18 visual systems made it possible to operate the display in an area of interest mode. Essentially, this consisted of establishing a TMB target as the center of the AOI and slaving the optical pickup probe to continuously view the target. In turn, the AOI image was displayed at its proper position with respect to the ground and the aircraft attitude. Several targets were programmed and were selectable from the instructors console.

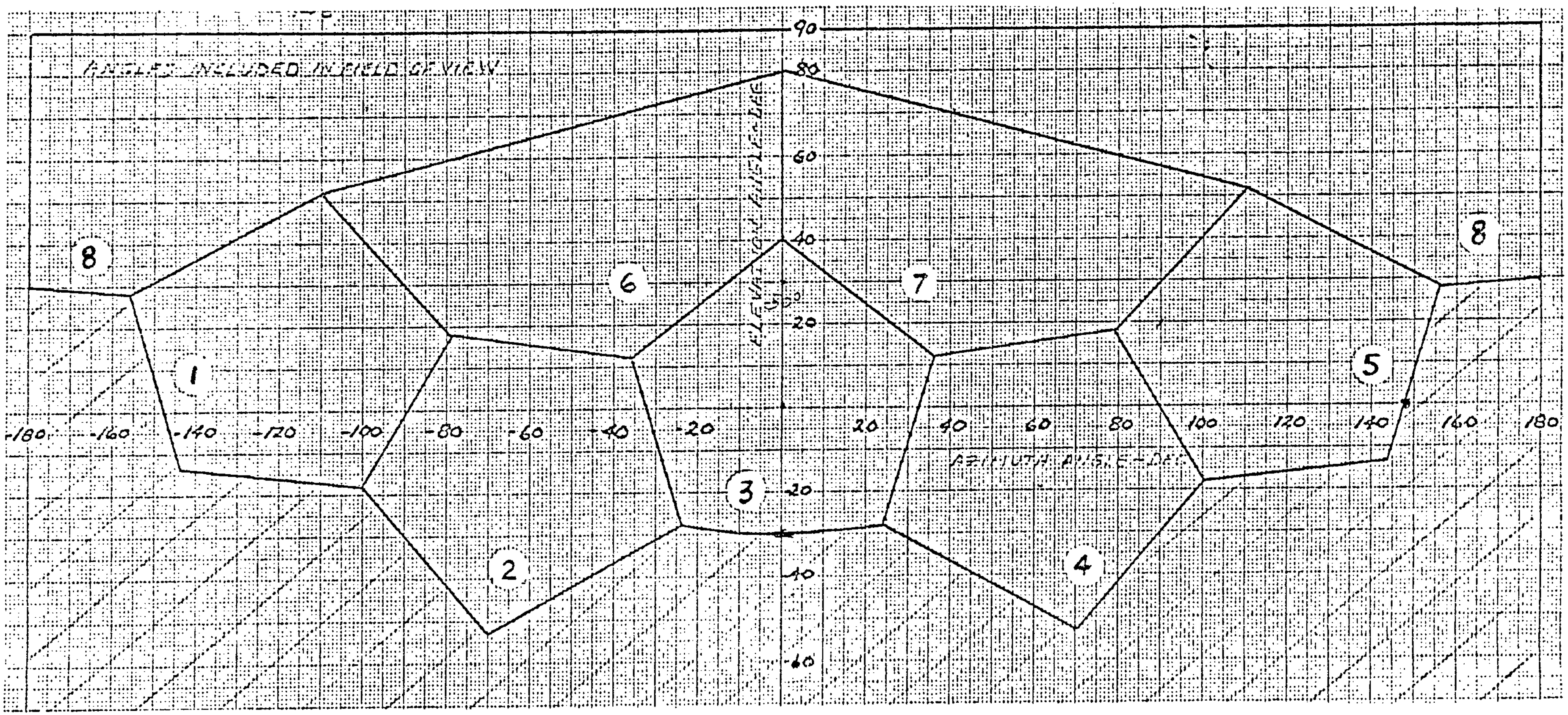


FIGURE II-11 SAAC WINDOW NUMBERING SYSTEM

(4) Advanced Instructional Features

This system included instructor consoles which provided the usual assortment of repeater instruments, failure mode insertion controls, and system monitoring equipment. The console also included a calligraphic CRT system. This system not only included the more standard type computer graphics (stores, information, initial flight conditions, terrain plots, etc.), but also presented a three-dimensional, continuous representation of the aircraft attitude with respect to the ground target. Console switches were provided for selection of the preprogrammed targets. Two console video displays were provided; one showing front window STG imagery, the other showing AOI terrain model imagery.

(5) Kinesthetic Simulation

Kinesthetic cueing was provided by a motion platform, a seat vibration system, a G-suit, and a G-seat. The motion platform was a six DOF, six post (60 inch stroke) synergistic system. Sustained G-simulation was provided by a G-seat and G-suit in the cockpit. The G-seat used 29 air operated bellows (14 seat, 9 back, and 3 in each thigh panel) and an active lap belt to provide both onset and sustained acceleration cues. G-suit simulation provided essential cues during high G maneuvering.

d. CIG/Flat Screen Projection System

The CIG/Flat Screen Projection System consisted of a single cockpit mounted on a limited three DOF motion platform. Three rear projection flat screens were floor mounted in front of the cockpit. The images were projected by three light valve projectors. The visual scene was produced by means of a CIG system which provided a 2-D perspective image of a 3-D digital environmental model stored in computer memory.

(1) Visual Generation

CIG for this device approximated the generation techniques for the other CIG system. Specific differences of this system were in display techniques, edge storage capacity (10,000 edges), instantaneous display capacity (1024 edges), the addition of color in sixty four shades, and number of channels (3 versus 7). The visual scenes were generated by approximating a set of planar faces for each object to be displayed. Each face was defined by a set of edges and was assigned a color. As the simulated aircraft moved through the environment, only the edge data in the immediate vicinity were retrieved from core for processing. This process maximized the edge display capability by elimination of unneeded information. The edges were mathematically transformed into numerical data representing the geometric projection of the 3-D model onto the 2-D viewing screens. This 2-D model was then converted into a CRT raster line format, assigned color code and channel number, and transformed into an analog video signal for projection by the light valve projector.

(2) Visual Display

The output of the CIG system consisted of three channels, each of which had three video signals (red, green, and blue). Each channel was then projected on to a rear-projection screen, via reflective mirror, by a light valve projector. The three screens were positioned to provide a nominal ± 105° horizontal by ± 30° vertical FOV.

3. CONCEPTS OF PHASE I (TECHNICAL) EVALUATIONS

a. Introduction

Phase I evaluations were only conducted on the three Air Force devices. The major objectives of the evaluations were to document technical performance and visual system features. Technical performance can be measured using several methods and parameters. Those tests described below were selected as the most appropriate because of their relationship to pilot performance and commonality between devices. A complete list of both common and peculiar tests is contained in Volume 2. System features applicable to the air-to-ground mission (e.g., weapons delivery scoring, ground impact, initializations, etc.) were documented as to their availability. The evaluation of the usability of these features is contained in the Phase II Operational Evaluation results.

The ideal visual display system for a flight simulator would present an image to the pilot which is indistinguishable from the real world scene in brightness, color, detail, perspective, FOV, etc. Such a display is not possible within present technology and may never be possible. Determining how closely a given display approaches the ideal was the major objective of these tests.

Tests for modulation transfer function give a measure of how well the display presents detail. Photometer measurements reveal display brightness and, when taken of a gray scale, give an additional measure of the display's ability to present detail. Distortion tests reveal perspective errors, distortion, and show the display's FOV. Additional tests were included which measured whether an object appeared in the display at the appropriate place and time.

b. Visual System Features

The following visual system features were documented on each of the three Air Force systems:

(1) Ground Terrain Display Format

How much ground terrain was displayed within the FOV of the display?

(2) AOI Slew

In systems presenting an AOI format, how was the AOI moved within the FOV of the display?

(3) Concurrent Display

What other images could be displayed simultaneously with the ground image (e.g., another aircraft, background terrain, missiles, gunsight)?

(4) Mission Monitoring

What capability does the system provide for monitoring pilot or aircraft performance or for monitoring the pilot's visual imagery at the console?

(5) Weapons Delivery Scoring

What weapons scoring capability does the system have?

(6) Varying Ceiling and Visibility Conditions

Does the system have the capability to vary the ceiling and visibility conditions?

(7) Moving Target

Can the system generate and display a moving model?

c. Technical Performance Tests

The following technical performance tests were accomplished on the applicable major system(s):

(1) System Static Resolution/Modulation-Transfer Function (MTF)

Modulation transfer function for optical and visual systems is in many ways analogous to frequency response for audio systems. To measure the frequency response of an audio system, a series of increasing frequencies at constant amplitude is applied to the input of the system, and the output amplitude is measured for each input frequency. Ideally, since the input amplitude is kept constant for all frequencies, the output amplitude should also be constant. In reality, the output varies as a function of input frequency, and beyond some frequency the output goes to zero. A chart of the output amplitude versus the input frequency is a measure of how faithfully the audio system reproduces the input signal. For audio systems, the input frequency is measured in cycles per unit time; for electro-optical systems, the input is a spatial frequency measured in cycles per unit distance. For audio systems, the amplitude is usually measured in volts; for optical systems, the amplitude is measured as the peak-to-peak brightness difference between the brightest and darkest parts of the image. Constant input amplitude for a series of spatial frequencies means that the brightness of both the brightest and darkest parts of the object pattern is kept constant. Beyond some input spatial frequency, no features are distinguishable in the reproduced image, and this frequency is termed the limiting resolution of the system. At spatial frequencies just below the limiting resolution, features are distinguishable in the reproduced image, but the brightness difference between black and white is small. A plot of the brightness difference in the reproduced image versus the spatial frequency is termed the modulation transfer function and is one measure of how faithfully the reproduced image resembles the original scene. Generally modulation transfer at a given spatial frequency is expressed as a percentage of the modulation transfer at some very low spatial frequency. An ideal optical system would have 100% modulation transfer to beyond the limiting response of the human eye.

There are several standard methods for expressing spatial frequencies. In optics, the usual standard is line pairs per millimeter. A line pair consists of one white line and one black line side-by-side. In television the usual standard is lines per raster height. One line is one black or white line so that one line pair in optics equals two TV lines in television. Raster height is used as the unit distance in television since the image may be displayed on any size CRT, and using raster height permits a fairly direct comparison of the quality of two displays. For some special television systems where the nominal viewing point is known and fixed, a more useful method of expressing spatial frequency is in terms of the angular subtense at the eyepoint of one TV line. This method allows a more direct comparison of two displays whether a given viewing area originates from a single CRT or from several mosaicked CRTs. Also, the angular subtense at the eyepoint can be related directly to a real-world scene in which an object of a given size is viewed from a given distance. For instance, a three-foot object viewed from 1,000 feet subtends an angle of 10 arc minutes at the viewer's eye. Under static conditions, high contrast, and long narrow objects, the smallest object visible to the normal human eye subtends an angle of approximately one arc minute. It should be noted that a high spatial frequency corresponds to a small angular subtense.

(2) Image Generator Static Resolution/MTF

A plot of the system MTF is an indication of how well the display reproduces the original scene, but it does not indicate where any degradation takes place. The image generator test eliminates the display from the system and plots the MTF of the model-board camera or computer image generator and the distribution electronics. Measurements are taken of the peak-to-peak video amplitude at a convenient point near the display. It should be noted that this video amplitude is not expected to be proportional to the brightness difference in the original scene. It is standard practice to add compensation to the video amplifiers to correct for limitations in the display.

(3) Display Static Resolution/MTF

The MTF of the display alone is measured by inserting an artificial resolution test signal into the video. The brightness difference between black and white is then measured in the display in the same manner as for the system MTF. Again, an ideal display would have a constant brightness difference for increasing spatial frequency to beyond the limiting response of the human eye. Any variation from this ideal is due to limitations in the display and its electronics. If the point where the video test signal is inserted is the same as the point where the image generator video was sampled in the previous test, the two curves can be combined by multiplying their values point by point. The resulting curve should closely approximate the system MTF from the system static resolution/MTF test.

(4) Image Generator Dynamic Resolution/MTF

Both television cameras and CRT displays have lag characteristics which can greatly reduce resolution and modulation transfer when an object moves within the field of view. It would be best to measure this reduction due to object motion by performing a test on the display itself; however, present techniques for doing so are limited and of questionable accuracy. However, tests for dynamic resolution of the camera are quite satisfactory and quite informative since most of the lag is in the camera.

(5) Brightness, Gray Scale, Contrast, Shading

A daylight scene in the real world contains elements which vary in brightness from a few foot lamberts (a railroad tunnel) to many thousands of foot lamberts (sand, snow). There is an infinite variety of combinations of brightness and hue which aids in differentiating objects. No visual display for a simulator can possibly match this wealth of information and detail.

A monochrome display, such as those evaluated during Project 2235, permits recognizing objects on the basis of size, shape, and brightness variations, but not color. The MTF measurements provide a quantitative measure of the display's ability to present size and shape information. But MTF measurements are always taken on a scene at maximum contrast from the whitest white to the blackest black. Any adjacent elements which differ in brightness by any amount less than the maximum will be less readily distinguishable than adjacent elements at maximum contrast. In fact, if the brightness difference between adjacent elements is relatively small, they may be indistinguishable regardless of how large the elements are, expecially in the presence of noise in the display. One rule of thumb states that adjacent elements should have a relative brightness of 1.414 to be readily distinguishable. (This ratio leads to a logarithmic gray scale.) Another rule of thumb, based on human physiology, states that in order to provide enough detail, a display should be capable of presenting ten distinct shades of gray. These two rules taken together imply that a display should be capable of a maximum contrast ratio of at least 23 (1.414 to the ninth power). Any ratio less than this means that the display is capable of fewer gray steps or, that adjacent elements of a ten-step gray scale may be difficult to distinguish, especially if the elements are small.

Display brightness, gray scale, and contrast are closely linked. Generally, the black level on a display can be set anywhere from near white to below detectability to the human eye. It is usually set to a sufficiently high brightness level to wash out extraneous light and to be visible to the human eye without an extended dark adaptation period. For a given black level, doubling the display brightness doubles the contrast and permits two more logarithmic gray shades. This last statement is really an approximation since the added brightness may force an upward adjustment of the black level because of the added extraneous light. A corollary to the above discussion is that for a given maximum brightness level, doubling the black level reduces the contrast by half and permits two fewer logarithmic gray shades.

Shading is not quite as closely linked to the other measurements, but a bad shading characteristic can be very distracting to the viewer. Ideally, if a camera is observing a featureless, evenly lighted scene, the display should present it without brightness variations. Actually, because of vignetting in the optics, variations between CRTs in mosaicked display, and the geometry of the display, brightness variations do occur. How noticeable or distracting these variations are depends on how great the variation is and how abruptly it takes place. As with the gray scale, it takes a variation of about 1.414 to 1 to be noticeable if the areas are close together. For widely separated areas with gradual variation in between, the brightness ratio can approach 2 to 1 without being objectionable.

(6) System Geometric Distortion, AOI Field of View, and AOI Dynamic Envelope Size

Shapes, sizes, distances, and proportions should always appear in the display as much as possible as they would in the real world. Any deviations are termed distortion. Distortion can be measured by generating a known geometric pattern at the image generator (computer or model board camera) and measuring the angles from the viewer's eyepoint to specified points in the displayed image. The displacement of these points from where they should be is a measure of the distortion in the system. The trend of displacements over a large area reveals expansion or compression of the scene, bending of lines, etc.

AOI field of view and AOI dynamic envelope size show the size of the AOI and the extent of its mobility within the display field of view. These tests are included with geometric distortion because the test setups are identical.

(7) System Interwindow Continuity

Display distortions are particularly objectionable when they occur abruptly. Mosaicked displays are particularly susceptible to abrupt distortions at the joints between display sections. The distortions take such forms as straight lines which change direction at a joint, objects which jump suddenly as they cross a joint, and objects which change apparent distance as they cross a joint. As in the previous distortion test, the angles are measured with a theodolite, and the distortions are calculated using vector mathematics.

(8) AOI Edge Transition

Present camera/model technology does not permit presenting complex detail from a TMB over the entire FOV of the display. Instead, the most important details are presented in that portion of the FOV which is of most current interest, the AOI. This AOI should ideally be blended smoothly into the background image over a viewing angle of several degrees. The more gradual the blend, the better the visual effect; but a gradual blend reduces the size of the AOI. As with many features, some tradeoff is involved.

(9) Target Image Location Dynamic Lag

All parts of an image should appear in the visual display at their proper location at the proper point in time determined by the aircraft flight dynamics and the control inputs. However, lags are introduced by servo response times, computer calculation times, iteration rates, display frame times, etc. The total lag at any given time will depend on the maneuver being performed and the time coincidence of the maneuver with the computer iteration and display frame times. The complexities of measuring the total lag on a given system were such that this test was not accomplished on any of the simulators for Project 2235. It had not been attempted on any earlier systems.

(10) System Rate Accuracy

The visual cues presented to the pilot should indicate the same velocity that the simulated aircraft is flying. The cues will be correct if the display is undistorted and, in the case of a TMB system, if the model board camera moves at the proper scaled velocity. Since distortion is measured in another test, the check of rate accuracy reduces to timing the travel of the model board camera.

4. CONCEPT OF PHASE II (OPERATIONAL) EVALUATION

a. Phase II Overview

Phase II consisted of pilots' evaluations of the selected devices. The systems' configurations were modified, as previously outlined, in order to support the evaluation of air-to-ground weapons delivery tasks.

System capabilities and limitations were identified by using the performance of a specific task in real-world flying as a standard. If deviation from this norm was observed, a determination was made as to why performance was altered, to what extent it was altered, and in what manner the system's limitation or anomaly was overcome.

In addition to the Phase II project manager, TAC obtained six experienced, mission ready fighter pilots (five from TAC, one from AFSC) representing the following weapons systems: F-4, A-7, F-105, and F-100. See Table II-1 for a summary of the evaluators' individual backgrounds. Throughout the evaluation of each system, the pilots were requested to maintain a minimum amount of interaction with respect to discussing simulator features or task performance so that a maximum amount of individuality of opinions could be preserved. Joint discussions were held at the end of each system evaluation.

PILOT NO.	EDUCATIONAL BACKGROUND	FLYING TIME	AIRCRAFT FLOWN	COMBAT EXPERIENCE	SIMULATOR TIME
4	B.S. Aero Eng.	3000 Hrs.	F100C/D, F101B, F4C/D/E, F102, T37, T38	F4D	450 Hr, Includes NASA DMS, VAMP, F4 AOI, MACS II and III, T4G EPT, AGM 12
1	B.S. Eng. Mech Aero	1400 Hrs.	A7D, AT33 T37, T38	A7D	200 Hrs.
6	B.S. Eng Aero Eng	1600 Hrs.	F4C/D/ESLAT, T37, T38	F4D/E	450 Hrs. Including NASA DMS, TAC ACES
5	B.S. Mil Sc MBA Pub Admin	3000 Hrs.	F105G/D, T38 T37, T33, T41	F105	100 Hrs. Including AGM 12
2	B.A. Soc Sci	2000 Hrs.	F4, T37, T38	F-4	250 Hrs.
3	B.A. PE and Health	1800 Hrs.	A7, AT33, A37, UC123K, T37, T38	A-37 UC123K	200 Hrs.

TABLE II-1 - PHASE II PILOT EVALUATOR'S BACKGROUND

Three briefers, experienced in visual simulation, were selected to brief, control, and debrief the pilots on each simulator sortie.

The various contractors and local organizations provided the following support: console operators to assist the briefer during console operation, maintenance technicians to perform any required adjustments, and engineering support and contractor technical representatives for consultation. The evaluation process itself started with a mission briefing in which the tasks to be analyzed on that particular mission were discussed. The mission itself, (lasting from 45 minutes to 1.5 hours) was then flown and pilot comments were recorded via pilot/briefer intercom. A thorough debriefing followed. It consisted of discussion and completion of a questionnaire containing both numerical ratings and narrative comments.

b. Mission Briefing

The mission briefing began with an overview of the flight and a summary of the objectives to be accomplished. A detailed description followed in which the briefer acquainted the pilot with the tasks to be performed, and the specific cues and references used for the task analysis (See Figures II-12 through II-23 for Mission Briefing Guide contents).

Judgment of task performance was aided by an analysis of spatial orientation cues and specific reference characteristics. The spatial orientation cues enabled the pilot to determine the aircraft's flight dynamics and location in the environment. See Table II-2 for the definition of spatial orientation cues rated. Various specific reference (items, objects, or features in the visual scene) characteristics were rated by the pilots during the mission and debriefing. See Table II-3 for the specific reference characteristics rated.

During the mission a briefer was at the console at all times to direct the mission, discuss and record ideas and comments, and generate further evaluation on a real-time basis. In addition, comments made during the mission were recorded on tape, and a computer printout, when available, recorded weapons delivery parameters and scores.

Attitude	The degree to which the necessary pitch, roll, and yaw cues can be obtained from the visual scene. (Can you tell your pitch, roll, yaw?)
Direction	The degree to which the aircraft's direction can be determined with reference to the visual scene. (Can you tell which direction you are going?)
Speed	The degree to which the necessary speed cue is available in the visual scene. (Can you tell how fast you are going?)
Altitude	The degree to which the aircraft's distance from a given object can be determined from the visual references. (Can you tell your height above the ground?)
Distance	The degree to which the aircraft's distance from a given object can be determined from the visual references. (Can you tell your distance from another object?)
Location	The degree to which the evaluator's aircraft location can be determined relative to the visual scene. (Can you tell where you are located?)
Lineup	The degree to which the aircraft's alignment with an object in the visual scene can be determined. (Can you tell if you are lined up with an object?)

TABLE II-2 - SPATIAL ORIENTATION CUES

Size	The degree to which the size is ascertainable, proportionally correct, and can be used as a visual cue. (Is the object the correct size?)
Shape	The degree to which the shape is ascertainable, proportionally correct, and can be used as a visual cue. (Is the object the correct form?)
Detail	The degree to which the detail is sufficient to use the object as a visual reference. The detail does not have to represent real-world conditions as long as it allows an adequate representation of the object. (Does the object have enough parts/pieces?)
Clarity	The degree to which the object is clear and can be used as a visual reference. (Is the object too blurred or too sharp?)
Movement	The degree to which the movement is sufficient to use the object as a visual reference. If the object is fixed, it should have no dynamic movement and rated excellent if it remains stationary. If the object should move, its movement should be realistic to the point that it is not unusual or distracting. (Does the object move as required?)

TABLE II-3 - SPECIFIC REFERENCE CHARACTERISTICS

Position	The degree to which the object is correctly positioned. (Is the object in the correct place?)
Environment	The degree to which the overall objects' environment is realistic and allows the proper use of the visual reference. If the surrounding environment should partially conceal an object, then it should be rated for that obscuring environmental characteristic. However, if an object should be clearly discernable, the environment should be rated for the ease which it allows the object to be located. (Does the object fit into the surroundings?)

TABLE II-3 (CONTINUED)

c. Missions

The mission scenarios were determined by the specific tasks to be analyzed. Ten sorties were flown with task complexity and environmental conditions graduated in degree of difficulty. To minimize the effects of varying motion cues between systems, assessment of each task was performed with and without motion cues.

The first sortie in each device consisted of an orientation to the device's flight characteristics and visual presentation. Tasks performed included takeoff, aerobatics, approach to stalls, slow flight, straight-in approaches, glide-path control, overhead traffic patterns, closed traffic patterns and normal landings (reference Figure II-13).

The second sortie was devoted to familiarization with the device's weapons delivery parameters on a conventional gunnery range (reference Figure II-14). Simulated ordnance for all missions consisted of low drag bombs and 20mm or 30mm cannon. Tasks performed included box patterns, roll-ins, low-angle bomb deliveries, high-angle bomb deliveries, strafe deliveries, and recoveries (reference Figure II-15).

In general, the next four sorties consisted of an in-depth analysis of low and high-angle events on a conventional gunnery range and an introduction to tactical operations. (Sortie progression varied slightly between devices; see Volume 2 for exact mission descriptions.) Weapon deliveries progressed from box patterns to curvilinear and pop-up approaches. The degree of difficulty of task performance was further increased by introducing variables such as decreased visibility and increased cross winds which varied in velocity and direction from mission to mission (reference Figures II-16 and II-17).

Missions seven and eight concentrated on tactical deliveries in tactical environments. Night operation was also begun involving takeoffs and landings as well as night weapons delivery familiarization. Tactical considerations included the following: terrain masking, enemy defenses, attacking a moving target, restricted attack headings, random patterns, and reattacks (reference Figures II-18 and II-19).

The last two missions included more tactical deliveries and traffic patterns during day and night conditions. Low-level navigation was flown in two of the devices to a specific target with additional deliveries made striking targets of opportunity. All facets of formation flying were attempted in two devices, including mutual support in an air-to-ground environment (reference Figures II-20 and II-21).

An eleventh sortie was flown in the first device evaluated to investigate the validity of the initial impressions of that system. This was done in an attempt to eliminate effects of the first exposure to a simulator permitting air-to-ground weapons delivery and to use the experience gained during the three systems evaluations on this first system (reference Figure II-22).

Each pilot flew approximately two hours in the 2B35 device. This additional evaluation was primarily intended to determine the effect of a 1000 edge, color CGI presentation and a reduced FOV on task performance. Tasks included takeoffs and landings, aerobatics, and representative conventional gunnery tasks and tactical deliveries (reference Figure II-23).

All missions progressed at a rate acceptable to the pilot. If a briefer or pilot decided a task needed to be reflown, time was provided.

d. Mission Debriefing

Immediately following the mission, the pilot, briefer, and a technical representative debriefed the mission. The briefer and technical representative kept their comments to a minimum to preserve the pilot's independent judgments and original opinions. Using pilot comments from recordings, briefer's notes, and weapons delivery printouts, the mission was reviewed in detail. Questions were posed to the technical representative to clear up any lack of understanding of a particular issue or occurrence.

After reviewing the rating criteria (See Table II-4), the pilot then completed a questionnaire (reference Volume 2 for sample questions). In addition to tasks performed, the questionnaire solicited comments in related areas such as motion cueing, possible safety hazards, physiological effects, visual correlation, and technology comparisons. All tasks performed were numerically rated and documented with supporting narrative comments.

e. Phase II Measurement

Use this guide to brief and control each mission.

1. During the mission, evaluate the tasks and references as listed on the appropriate analysis form for the respective mission. Record as many of the pilot's comments on the Mission Remarks Log as time will allow. Insure that the tape recorder is operating. Maintain the Weapons Log, if applicable.

2. At the completion of the mission, the pilot, briefer, and technical representative will debrief the mission. Use the notes and recording obtained during the mission, as appropriate. Discuss the inflight comments and derived opinions sufficiently so that the technical representative fully understands any issues that may subsequently arise. The technical representative has been instructed to have limited participation in this briefing so that the pilots will continue to offer original opinions concerning the visual scene.

3. After the debriefing, the pilot will complete the debriefing questionnaire for the mission just flown.

4. Give all paperwork to the Phase II manager.

Figure II-12 BRIEFING GUIDE INSTRUCTIONS

a. Time: 90 minutes

b. Cockpit: B only with right seat support

c. Motion: On

d. Initialization: Runway; WX Cat A; Winds Calm

e. Flight Area: Airfield Complex

f. Purpose: Familiarization with simulator flight characteristics and visual presentations. Pilot should be able to fly the simulator at the completion of this sortie.

g. Description	Time Guide
Takeoff, depart the pattern area. Fly the aircraft and obtain a feel for the controls and instrumentation. Select ground references for airwork and aerobatic tasks.	+ 20
Perform lazy eights, chandelles, slow flight, stalls, spins, and a vertical recovery.	+ 40
Change to WX Cat B and perform aileron roll, barrel roll, cloverleaf, loop, immelmann, split-s, and cuban eight.	+ 60
Return to the airfield and perform a straight-in approach, low approach, and missed approach. Re-enter initial and fly multiple VFR overhead and closed patterns with touch-and-go and full stop landings (at least two of each).	+ 90

Figure II-13 SAMPLE SORTIE PROFILE
(Mission I, CIG/Optical Mosaic)

a. Time: 45 minutes

b. Cockpit: B only

c. Motion: 50% On - 50% Off (Random)

d. Initialization: Conventional Range; WX Cat B; 10 Knot Crosswind

e. Flight Area: Conventional Range

f. Purpose: Analyze low angle events on the conventional range. At the completion of this mission, the pilot should be able to form definite opinions about the suitability of the visual scene to allow performance of low angle weaponry tasks.

g. Description	Time Guide
Use the reset function throughout. Fly one pass in each of the following events for refamiliarization (Motion On):	
Low Angle Strafe	
Low Level Bomb	
10° Skip	
15° Low Angle Bomb	+ 10
Perform each of the following tasks at least three times, and use the allotted time fully (Motion On or Off).	
Low Angle Strafe	
Low Level Bomb	+ 20
10° Skip	
15° Low Angle Bomb	+ 30
Perform each of the tasks at least three more times (Motion On or Off)	
Low Angle Strafe	
Low Level Bomb	
10° Skip	
15° Low Angle Bomb	+ 45

Figure II-14 SAMPLE SORTIE PROFILE
(Mission 2, CIG/Optical Mosaic)

Weapons Delivery	BASE Alt (Ft)	BASE Airspeed (KIAS)*	RELEASE Alt (Ft)	RELEASE Airspeed (KIAS)*
Low Angle Strafe (5-15°)	3000	250/350	2400-2000 Slant Range	300/400
Low Angle Bomb (10°)	3000	250/350	500	300/400
Low Angle Bomb (15°)	4000	250/350	800	300/400
Low Angle Low Drag (20°)	4000	250/350	2000	300/450
High Angle Strafe (30°)	7500	220/300	3600-3100	300/450
Dive Bomb (30°)	7500	220/300	3500	300/450
Dive Bomb (45°)	10500	200/300	5000	300/450
Dive Bomb (45°) (Hi Alt Rel)	12500	200/300	7500	300/450
Dive Bomb (60°)	13000	200/300	8000	300/450

*Note: The first airspeed is for the CIG/Optical Mosaic/ TMB/Dome Projection and the second for the TMB/ Optical Mosaic and 2B-35.

Figure II-15 WEAPONS DELIVERY PARAMETERS

a. Time: 60 minutes

b. Motion: Initially On, then 50% Off - 50% On

c. Initialization: 5000: 1 Board; Runway Area; Clear Visibility; Winds - 090°/10 knots

d. Flight Area: Northeast quadrant of 5000: 1 board

e. Purpose: Analyze low angle events performed against a conventional target. At the completion of this mission, the pilot should be able to form definite opinions about the suitability of the visual scene to allow performance of low angle weaponry tasks against a conventional target.

f. Description	Time Guide
Motion Off Run: 15° LAB pass and recovery	+ 05
With motion on or off, fly one pass in each of the following events: LAS, 10° SKIP, 15° LAB, 20° LALD.	+ 15
Then fly at least three passes in each event. Fly additional passes, time permitting.	+ 40
Select the remaining motion setting and fly at least three additional passes in each event.	+ 60

Figure II-16 SAMPLE SORTIE PROFILE
(Mission 4, TMB/Dome Projection)

a. Time: 60 minutes

b. Motion: Pilots 1, 3, 5 - Off; Pilots 2, 4, 6 - On

c. Initialization: 4000:1 Range Area; Diamond range, base leg for DB on right circle (02); AOI centered on right bomb circle.

d. Flight Area: Diamond and conventional gunnery ranges

e. Purpose: Analyze high-angle events as performed on a conventional range. At the completion of this mission, the pilot should be able to form definite opinions about the suitability of the visual scene to allow performance of high-angle weaponry tasks on a conventional range.

f. Description	Time Guide
With motion off or on, establish a left-hand box pattern on the right side of the diamond range, and perform each of the following events three times:	
30° DB (02) 30° HAS 45° DB 45° HADB	+ 25
Proceed to the conventional range, and perform each of the following events three times:	
30° DB (04) 30° HAS 45° DB 45° HADB	+ 50
Use the remainder of the hour to perform several passes in each of the following events on the conventional range:	
15° LAS (08) 15° LAB (03)	+ 60

Figure II-17 SAMPLE SORTIE PROFILE
(Mission 6, TMB/Optical Mosaic)

a. Time: 60 minutes

b. Motion: On

c. Initialization: 1500:1 board; appx 7 mi final; Clear Visibility; Simulated Ceiling at Maximum Altitude (3000 ft); Winds - calm

d. Flight Area: 1500:1 Board

e. Purpose: To introduce the pilot to the takeoff and landing capabilities of this visual system and to analyze low angle events in a tactical environment. At the completion of this mission, the pilot should be able to perform takeoff and landing tasks and should be able to form definite opinions about the suitability of the visual scene to allow performance of low angle weaponry tasks in a tactical environment.

f. Description	Time Guide
Motion Off Run: 50 ft low approach	+ 05
Turn motion on and perform a straight-in 50 foot low approach. Re-enter, and perform another 50' low approach. Depart the runway complex heading west.	+15
Locate the Suspension Bridge and the Gravel Pit. Locate the Bulldozer on a hill in the Gravel Pit. Perform one pass in each of the following events against the Bulldozer: 20° LALD (modified due to maximum altitude restriction), 15° LAB, 10° SKIP, LAS.	+25
Locate the Strafe target, and perform three passes in each of the following events, using a curvilinear approach: LAS, 10° SKIP.	+35
Locate the two large aircraft near a hanger on the Southwest side of the airfield. Attack the one furthest to the West using three passes in each of the following events, using a curvilinear approach: 15° LAB, 20° LALD.	+30
Re-enter initial, and perform at least two VFR Overhead approaches, closed patterns, and touch and go landings.	+60

NOTE: Brief the 150 ft/14ft altitude restriction areas on the 1500:1 board.

NOTE: Use caution for several 300' trees on final approach (2-3 mi).

Figure II-18 SAMPLE SORTIE PROFILE (Mission 7, TMB/Dome Projection)

a. Time: 60 minutes

b. Motion: 50% - On; 50% - Off (1,3,5 - On/Off; 2,4,6 - Off/On)

c. Initialization: 4000:1 Range Area; 5 NM southwest of runway (06); G-Seat off; AOI centered on small white T-shape building west of airfield.

d. Flight Area: Tactical target areas and 1500:1 board airfield.

e. Purpose: Analysis of tactical range high-angle weaponry tasks and traffic pattern tasks.

f. Description	Time Guide
With motion on or off, locate the tactical target, as briefed, and perform three passes in each event using random attack patterns:	
30° DB 30° HAS 45° DB 45° HADB	+ 15
Locate tactical targets of opportunity, as briefed, and perform three passes in each of the following events:	
30° DB 30° HAS 45° DB 45° HADB	+ 30
Select the other motion setting, initialize 09, 6 mile final to Runway 17 on the 1500:1 portion of the model board. Perform a straight in low approach, go around, and depart the runway area using right hand traffic. Re-enter initial and perform three overhead VFR approaches and closed patterns. Locate the taxi intersection, 2/3's of the distance down the runway and perform three passes in each of the following events using a mix of curvilinear approaches and pop-up patterns:	
20° LALD 15° LAB 15° LAS 10° SKIP	+ 60

Figure II-19 SAMPLE SORTIE PROFILE
(Mission 8, TMB/Optical Mosaic)

a. Time: 60 minutes

b. Motion: 50% Off - 50% On (Selected)

c. Initialization: 1500:1 board, appx 7 mi final; reduced visibility (7 mi); simulated ceiling at maximum altitude (3000 ft); winds - 135°/10 knots

d. Flight Area: 1500:1 board

e. Purpose: To analyze low angle events using pop up patterns and curvilinear approaches in a tactical environment. At the completion of this mission the pilot should be able to form definite opinions about the visual systems suitability to allow performance of tactical approaches to targets using a combination of pop up, curvilinear, and low angle tasks.

f. Description	Time Guide
Motion off run: (Start the following mission)	+ 00
With motion off, perform a touch and go landing and depart the runway complex heading east. Locate a tank farm to the west of the runway and strike the short center tank using a restricted heading, pop up pattern, curvilinear approach, and 15° LAB pass, as briefed. Perform at least two additional 15° LAB patterns and two 10° SKIP passes against the tank.	+ 15
Locate a complex of five buildings northwest of the runway. Attack the building furthest to the east on an east to west heading. Perform at least two 20° LALD deliveries and two LAS deliveries.	+ 25
Turn the motion on, select night conditions, clear visibility, and return to the end of the runway complex and perform the following night weaponry tasks against the scored end of the runway (target is southern strobe on south R/W). Perform at least three passes per event using a mandatory minimum altitude of 200 feet: 20° LALD, 15° LAB, 15° LAS.	+ 50
Perform a night straight in approach to a touch and go landing. Execute a go around after touchdown, enter a closed pattern, and execute multiple overhead patterns and touch and go landings.	+ 60

NOTE: Runway lights are uni-directional.

Figure II-20 SAMPLE SORTIE PROFILE (Mission 9, TMB/Dome Projection)

a. Time: 60 minutes

b. Cockpit: B - Evaluator: A - Lead Pilot (15 minutes)

c. Motion: 50% On - 50% Off

d. Initialization: Williams Data Base, Airborne with lead aircraft, WX Cat A, Wind 060°/10 knots

e. Flight Area: Williams low level, then A-10 data base airfield

f. Purpose: To analyze formation tasks when performed against a detailed aircraft; to analyze low level tasks; to analyze approach and landing tasks (day and night). At the completion of this mission, the pilot should be able to form definite opinions concerning formation, low level, approach, and landing tasks.

g. Description	Time Guide
NOTE: Brief the pilot that the motion will be on and off during the formation portion, and solicit his opinion as to the effect of motion on the task difficulty.	
Unfreeze, and perform the following formation task (motion on/off): Close	
Continue the formation tasks for five minutes (motion on/off): Close	+ 15
Reinitialize at Williams AFB and fly a visual low level route until passing the second checkpoint (motion - on)	+ 35
Reload the A-10 environment and initialize on a GCA final at night, vis - 20,000', ceiling 1900' MSL (500' AGL). Perform a GCA approach and landing. Execute a visual touch and go landing (increase the ceiling to 2500'), and perform multiple closed patterns and night overhead patterns (motion - on)	+ 50
Change to day conditions and use the remainder of this mission to perform day VFR overhead patterns	+ 60

Figure II-21 SAMPLE SORTIE PROFILE (Mission 10, CIG/Optical Mosaic)

a. Time: 60 Minutes
b. Motion: On
c. Initialization: Runway; 10 knot wind; Limited Visability; "G" - seat: On; tank started; Slaved Visual.
d. Flight Area: Runway, town, and a conventional range area.
e. Purpose: To gather data on a variety of tasks as a method of determining the relative rating of the CIG/Optical Mosaic System during the previous ten sortie evaluation.

f. <u>Description</u> — <u>Time Guide</u>

Motion: On (All Pilots)
Start on the runway. Takeoff, depart the airfield complex, return to the final approach and perform a straight-in touch and go landing. Depart the airfield, reinitialize in the town area, and locate the moving tank. Attack the tank using a random attack and 30° DB pass. Reattack the tank using a 30° HAS pass. Depart the town. + 15

Initialize on the range. (Do not use the initialization feature between releases). Establish a left hand box pattern and perform the following tasks (one pass in each event for warm up):

15°LAB @ 800'	Standard Pattern	2 Releases
15°LAB @ 800'	Curvilinear Pattern	2 Releases
LAS @ 2000' Foul	Standard Pattern	2 Releases
LAS @ 2000' Foul	Curvilinear Pattern	2 Releases
30°DB @ 3000'	Standard Pattern	2 Releases
30°DB @ 3000'	Pop-up Pattern	2 Releases
		+ 45

Return to the runway area (fly - do not initialize) and enter initial. Pitchout and perform a touch and go landing. Perform multiple random attacks against targets of opportunity on the airfield (aircraft for score). Terminate with a full stop landing.

+ 60

Figure II-22 SAMPLE SORTIE
(Mission 11, Refly, CIG/Optical Mosaic)

a. Time: 60 Minutes (Order - P-4, P-5, P-6, P-1, P-2, P-3, B-1, B-2, B-3, B-4, all observe throughout).
b. Motion: 50 Minutes - Off; 10 Minutes - On.
c. Initialization: Runway; 10 knot wind; fog; moving cloud; haze; meat-ball; Off; "G"-system: On.
d. Flight Area: Runway and weaponry range areas.
e. Purpose: Brief familarization with the simulator's flight characteristics and visual presentation.

f. Description	Time Guide
Motion: Off (All Pilots) Start on the runway. Takeoff, depart the airfield complex, return to the final approach and perform a straight-in touch and go landing. Depart the airfield complex and proceed to the weaponry range. Perform an aileron roll and a loop while en route to the range.	+ 15

Establish a left hand box pattern and perform the following tasks:

15^{o}LAB @ 800'	Standard Pattern	2 Releases
15^{o}LAB @ 800'	Curvilinear Pattern	2 Releases
LAS @ 2000' Foul	Standard Pattern	2 Releases
LAS @ 2000' Foul	Curvilinear Pattern	2 Releases
30^{o}DB @ 3000'	Standard Pattern	2 Releases
30^{o}DB @ 3000'	Pop-up Pattern	2 Releases
45^{o}DB @ 4500'	Standard Pattern	3 Attempts

+ 45

Return to the runway area and enter initial. Pitch-out and perform a touch and go landing. + 50

Motion: On
Perform multiple random attacks against targets of opportunities. Terminate with a full stop landing.
+ 60

Figure II-23 SAMPLE SORTIE (Device 2B35)

Spatial Orientation Cue Analysis	Level	Specific Reference Analysis
Cue not applicable to task	Blank	Characteristic not applicable to specific reference
Totally inadequate capability to provide cue	1	Totally inadequate presentation of characteristic
Marginal capability to provide cue	2	Marginal representation of characteristic
Good capability to provide cue	3	Good representation of characteristic
Very good capability to provide cue	4	Very good representation of characteristic
Outstanding capability of device to provide cue. Does not need to improved upon.	5	Outstanding representation of characteristic. Does not need to be improved upon.

TABLE II-4 - PROJECT 2235 RATING SYSTEM

It is appropriate at this point to discuss the issue of Phase II measurement. The focus of the evaluation was to descriptively evaluate the individual capabilities (e.g., visual, potential to perform tasks, scoring, etc.) of each device and was not intended to compare the three simulator systems. Therefore, emphasis was placed upon qualitative subjective measurement in the form of pilot ratings and comments supplemented by pilot interviews.

Selection of an appropriate rating scale is a controversial issue. The number and definition of separate points on the scale selected always are subject to debate. On the one side, a small number of points reduces the number of rating options so that the rating answer is definite (e.g., yes/no, yes/maybe/no). However, it should be realized that fine discrimination information about a concept is lost as the number of rating points is reduced. The rater is forced to consolidate fine discriminations into a single rating point. Conversely, more rating points in a scale requires that the rater have a better knowledge of what each point represents as well as a good knowledge about the rating anchor points (end points and the mid-point of the scale). Opinion anchor points are the reference points (i.e., frame of reference or standard) that a rater uses to make a judgment about the concept being considered. A factor that is considered by the rater is his understanding of what is positive, negative or in the mid-point of the scale. These concepts are formed by his exposure to the simulator. Ratings can be affected by the following factors:

(1) Ordering Effect

The order in which the simulators were visited during Phase II would be expected to impact the ratings about the simulator. Concepts formed about the first simulator serve as reference points or standards for all succeeding evaluations. Thus, if time permits, it is highly desirable to revisit and obtain ratings on all devices. In Phase II, time and scheduling permitted a second visit to only the first facility. The order in which the three Phase II simulator facilities were visited was predicated upon availability.

(2) Recency of Exposure

Ratings taken immediately after exposure will frequently differ significantly from those ratings taken at longer intervals after exposure.

With the passage of time, factors which influence a rater become less distinct. In Phase II, ratings were made immediately after the pilots flew the simulator.

(3) Number of Exposures

The number of times that a rater is exposed strengthens his response to a given concept. The result is a reduction or tightening of the distribution of ratings given. During Phase II, evaluation pilots were given approximately ten sorties in each simulator and were asked to rate selected characteristics of the simulator after each sortie.

(4) Rater Characteristics

This factor is a major contributor to rater variability. Some raters tend to rate high, others low. However, most raters are relatively consistent. Research studies on rating scales have shown that raters tend to use the mid-points of rating scales as opposed to using the extremes. A method of reducing variability due to this factor is to provide the rater with a good understanding of the concept to be rated and a comprehensive definition for each point on the rating scale. In Phase II, the evaluation pilots were thoroughly briefed on the features to be rated and the use of the rating scale.

SECTION III

EVALUATION RESULTS

This section contains the results of the technical and operational evaluations for the three Air Force systems evaluated and a brief summary of the Navy system flown at the completion of Phase II. The major features and technical performance measurements for each approach to air-to-ground simulation are summarized under the technical portions of this section (Paragraphs 1a, 2a, 3a). Technical performance data for the CIG/Light Valve Projection (Screen) system was obtained from published contractor documentation. The technical procedures and observations performed to obtain the data are located in Volume 2. The operational capabilities, limitations and anomalies, proposed improvements, and potential capabilities for each system are described in the operational portion of this section (Paragraphs 1b, 2b, 3b). Specific evaluation missions and sample questionnaires are contained in Volume 2. In addition, paragraphs 1b(4), 2b(4), 3b(4) titled "Required/Optimized System Performance Characteristics and Potential Capabilities" pertain to the immediately preceding AF system. The discussions contained therein are departures from the data. They represent the opinions of the authors and are based on the experience and knowledge gained by them throughout the Project.

1. CIG/OPTICAL MOSAIC RESULTS

a. Technical Results

(1) Visual System Features

(a) Ground Terrain Display Format

The CIG/Optical Mosaic System provided a full FOV presentation of $\pm$ 150° horizontally and + 110°, - 40° vertically. The display scene content was not limited or restricted to a smaller AOI within the FOV. All features of the environment data base were displayed simultaneously throughout the full FOV of the display with equal detail and resolution.

(b) AOI Slew

Not applicable in this system.

(c) Concurrent Display

The visual system concurrently displayed a ground scene and one airborne image such as another aircraft or a missile. This system did not have the capacity to simultaneously display more than one moving model (aircraft, missile, tank). Although the CA503 optical gunsight was not a part of the visual display system, it did provide an integral part of the visual cues available to the pilot.

(d) Mission Monitoring

Monitoring maneuvers and pilot performance were accomplished by the following means:

1. All cockpit instruments were repeated at the instructor station position.

2. A television camera in the cockpit was used to observe the pilot and a portion of the aircraft instruments.

3. Two CRT/graphic monitor systems were used to display all pertinent aircraft parameters, including the aircraft's flight path (top and side view) relative to the target and target location. Other graphic displays were also provided as described under scoring below.

4. Two repeater television monitors were located at the instructor station to display the CIG imagery from selected channels.

(e) Weapons Delivery Scoring

The visual system displayed a real time image of bomb and bullet impact. For scoring conventional range targets, such as the dive bomb circle or skip box, the graphic display presented target and weapon delivery information consisting of the following: for bombing, the relative positions of weapons impact; for strafe, the percentage of hits. Applicable aircraft flight parameters at the moment of release or fire were concurrently presented for both dive bomb and strafe. The parameters and score were available on an off-line, hardcopy printout.

(f) Varying Ceiling and Visibility Conditions

This system was capable of displaying a continuous ceiling and variable visibility. Ceiling height was variable from 100 feet to 99,900 feet in increments of 100 feet. Visibility was variable from 100 feet to 999,900 in increments of 100 feet.

(g) Moving Target

The CIG system generated and displayed one moving model which was activated from the instructor console without the pilot's knowledge. During this evaluation the moving model capability was used to simulate a lead or FAC aircraft, a SAM or a tank.

(2) Technical Performance Measurements

(a) Display Resolution

No test was run to specifically determine the limiting resolution of the display. The MTF curves (Volume 2), indicate a limiting resolution near four arc minutes.

(b) Scene Detail

The edge processing capability of the system is 2500 edges of scene detail. The design specification for the system required 2000 edges of processing capacity. The system was built with a 2500 edge processing capacity to assure capacity for the edges required for generation of the left-hand boundary of each raster. Also, some additional processing capacity was desired to allow for adjustment in the data base content as system overload is approached. The full 2500 edge processing capacity of the system was available and used for this evaluation.

(c) Contrast

Contrast depends greatly on the conditions under which it is observed. The gray scale test pattern used for measuring the system gray scale was a set of ten small patches in a large 50% Average Picture Level (APL) background. Under those conditions, the photometer readings indicate a contrast of only 6.9 (5.9/.85). This figure was surprising since the gray scale had a very satisfying visual appearance. It may be that some of the ghost images which increased the photometer readings at the black end of the scale were ignored by the human eye because they are at the improper distance. Measuring isolated gray patches of the CRT electronics gray scale test pattern produced a contrast ratio of 72.5 (5.8/.08). This ratio could be considered a limit since it was obtained with one window displaying an isolated patch of gray or full field black and all other windows turned off. Other conditions may be expected to produce any contrast ratio between these limits.

(d) Brightness

Highlight brightness measured from 5.5 to 6.1 foot lamberts (fl) at the centers of windows 1 and 4 (Reference Figure II-2 for window numbering).

(e) MTF

The MTFs for both vertical and horizontal resolution in windows 1 and 4 are presented in Volume 2. The image generator output amplitude was reduced at higher resolutions by the edge smoothing incorporated to improve the appearance of the scene. No edge smoothing was employed in the vertical direction, and the effect was to make the MTF remain high until the image approaches the dimension of a scan line. The peak-to-peak amplitude of the scene depended on the orientation of the image with respect to the scan lines. The curves for vertical MTF (reference Volume 2, Figures I-2 and I-3) split at higher resolutions to show the observed range of peak-to-peak amplitudes. Although the display showed obvious transitions from black to white, the image presented was a poor approximation of the programmed resolution pattern at less than approximately ten arc minutes.

(f) Display Channel Edge and Corner Resolution

There appeared to be little significant difference in resolution between the centers and corners of the windows (reference the MTF curves in Volume 2).

(g) Image Distortion

The azimuth and elevation angles to 26 data points in window 1 were converted to unit vectors. The angles between the vectors were then computed and compared to the theorectical values to give a measure of image distortion. The average displacement of the observed points from their theoretical location was less than 1/4 degree. The maximum displacement of .85 degree was found near the top corner of the window. The image within the window could be considered to be essentially distortionless. The angles between vectors to the same image points as they appear in two adjacent windows were also calculated to measure distortion across the joints. The average displacement along the three joints between windows 1, 2, and 4 was .79 degree with a maximum of 1.1 degrees near the lower end of the joint between windows 1 and 4. Data for all of the above was obtained with the computer using a set of constants different from what had been used for the Phase II evaluation. After the constants were changed, the displacements along the same three joints averaged .71 degree with a maximum of 1.15 degrees near the left end of the joint between windows 2 and 4. The joint between windows 2 and 6 averaged 1.8 degrees.

(h) Variation of Brightness

Readings on a 50% APL scene showed insignificant variation over windows 1 and 4 except at two points. Ten test points were grouped between 2.5 and 3.3 fl. The bottom right corner of window 1 measured 1.9 fl, and the left edge of window 4 measured 2.0 fl.

b. Operational Results

The results of the operational evaluation of the CIG/Optical Mosaic system that was evaluated are summarized and discussed under the following three headings: (1) Demonstrated Capabilities and Average Ratings; (2) Limitations, Anomalies, and Improvements; and (3) Significant Strengths. A final section is included, (4) Required/Optimized System Characteristics and Potential Capabilities, and is used to introduce a theoretically optimized system using CIG/Optical Mosaic technology.

(1) Demonstrated Capabilities and Average Ratings

The data collected during Phase II consisted of pilots' ratings and comments and project team members' observations. Since the quantitative data by itself might lead to erroneous conclusions about system capabilities, summarized pilot comments are added to the rating data in order to clarify the interpretation of the quantitative rating results.

(a) Task Accomplishment and Ratings

The 81 tasks which were performed during the Phase II evaluation are listed in Table III-1. The pilots were asked to rate each task with regards to the capability of the device to allow performance of the task. The rating scale used to rate the tasks, one (inadequate) to five (outstanding), was the same used for the spatial orientation and specific reference analysis. The total number of responses obtained for each task is listed under the column titled sample quantity. The average rating for all responses is listed under mean rating. The middle rating is listed under median rating while the most popular response is listed under the mode rating column. The standard deviation is also listed. In addition, a remarks column provides additional information concerning task performance.

All 81 tasks included in Phase II mission scenarios were accomplished by the CIG/Optical Mosaic system. The task ratings for this system were high and generally consistent (Note: relatively low standard deviations). The following statements incorporate the comments listed for specific tasks which are reported as limitations and are further addressed in paragraph (2) below. Takeoff/departure and approach/landing were rated high. It should be noted, however, that pilot comments indicated some difficulty in judging altitude and rate of descent in the flare. Visual navigation was accomplished in a very large gaming area but was generally too easy to perform (compared to real-world difficulty) due to lack of detail in the environment. Performance of weaponry patterns and roll-ins on controlled and tactical ranges was accomplished with little alteration. Some tasks were more difficult to perform than normal due to the discontinuity of images used for pilot cueing as they transitted seams between the pancake windows. Low and high angle weaponry events

TASK TITLES	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVI-ATION	PILOT/PROJECT MEMBER REMARK
TAKEOFF	6	3.5	3.5	3,4	1.05	Limited Surface Texture. No runway markers.
NIGHT TAKEOFF	6	3.5	3.5	3,4	1.05	Scene too bright.
DEPARTURE	6	3.5	3	3	.84	Lack of Surface Detail.
NIGHT DEPARTURE	6	3.5	3	3	.84	
STRAIGHT IN	6	3.8	4	4	.75	
NIGHT STRAIGHT IN	6	3.8	4	4	.75	
RADAR FINAL APPROACH	6	3.8	4	4	.75	
VFR OVERHEAD	35	3.9	4	4	.68	Lack of eighth window limits FOV.
NIGHT VFR OVERHEAD	28	3.4	3	3	.57	Scene too bright, excessive detail.
GLIDE PATH CONTROL	6	3.8	4	4	.75	
NIGHT GLIDE PATH CONTROL	6	3.8	4	4	.75	
GO AROUND	6	3.5	3.5	3,4	1.05	
NIGHT GO AROUND	6	3.5	3.5	3,4	1.05	Scene too bright.
CLOSED	42	4.0	4	4	.73	
NIGHT CLOSED	42	3.6	3	3	.66	Scene too bright.
REENTRY	47	3.8	4	4	.73	
NIGHT REENTRY	40	3.5	3.5	3,4	.68	
LOW APPROACH	12	3.7	4	4	.89	
NIGHT LOW APPROACH	12	3.7	4	4	.89	Scene too bright.
TOUCH AND GO LANDING	42	3.8	4	3,4	.75	
NIGHT TOUCH & GO LANDING	42	3.8	4	3,4	.75	Scene too bright.
FULL STOP LANDING	42	4.2	4	4	.62	
NIGHT FULL STOP LANDING	42	4.2	4	4	.62	Scene too bright.
LAZY EIGHT	6	3.7	4	4	.52	Section lines made task too easy.
CHANDELLE	4	3.3	3	3	.50	Not enough horizon cues.
SLOW FLIGHT	6	3.5	3	3	.84	
STALLS	6	3.5	3.5	3,4	.55	
VERTICAL RECOVERY	4	3.0	3	3	.82	Patchwork environment not large enough.
SPINS	6	4.5	4.5	4,5	.55	
AILERON ROLL	5	3.8	4	3,4	.84	
BARRELL ROLL	6	3.3	3.5	3,4	1.40	Insufficient horizon reference.
CLOVERLEAF	6	3.5	3.5	3,4	.55	
LOOP	5	4.0	4	3,5	1.00	
IMMELMANN	6	3.5	3	3	.84	
SPLIT S	5	3.8	4	3,4	.84	
CUBAN 8	6	4.0	4	3,4,5	.89	

TABLE III-1 - TASK ACCOMPLISHMENT AND RATINGS (CIG/OPTICAL MOSAIC)

TASK TITLES	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVIATION	PILOT/PROJECT MEMBER REMARK
FORMATION TAKEOFF	12	2.7	2.5	2	.78	Limited detail.
CLOSE FORMATION	18	2.6	3	3	.61	Depth perception difficult, overload distracting.
ROUTE FORMATION	12	2.8	3	3	.62	Overload distracting, seam distortion distraction.
CROSS UNDER	12	2.8	3	3	.62	Too little detail.
CLOSE TRAIL	16	3.3	3	3	.86	
EXTENDED TRAIL	8	2.5	2.5	2,3	.93	Hard to tell closure rate.
TACTICAL FORMATION	12	2.3	2.5	3	.78	Hard to tell lead's heading, lost sight at extended ranges.
FORMATION LANDING	6	2.7	2.5	3	.82	
BOX PATTERN	18	4.1	4	4	.73	Detail lost in window seam.
NIGHT BOX PATTERN	6	3.7	3.5	3,5	1.21	Too much light.
ROLL IN	18	3.2	3	4	1.00	Detail lost at window seam.
NIGHT ROLL IN	6	3.7	3.5	3,5	1.21	Too easy.
DIVE ANGLE ESTABLISHMENT	11	3.2	3	3	.60	Difficult for low angle events due to limited detail and texture.
NIGHT DIVE ANGLE ESTBLMT	6	3.3	3	2,4,5	1.03	
RECOVERY	18	4.2	5	5	1.04	Lack of eighth window prohibits viewing weapon impact, inflight SAM.
NIGHT RECOVERY	6	3.7	3.5	3,5	1.21	
LOW LEVEL BOMB	6	2.7	2.5	2,3	1.37	Limited detail and texture.
LOW ANGLE STRAFE	33	3.7	4	4	.98	Limited detail & texture. Foul line too distinct.
NIGHT LOW ANGLE STRAFE	33	3.7	4	4	.98	
10 DEGREE SKIP BOMB	23	3.6	4	4	.99	Little detail or surface texture, skip box too indistinct.
15 DEGREE LOW ANGLE BOMB	29	3.9	4	4	.69	Limited detail and texture.
NIGHT 15° LOW ANGLE BOMB	6	3.7	4	4	1.03	
20° LOW ANGLE LOW DRAG BOMB	53	3.9	4	4	.73	
NIGHT 20° LOW ANGLE LOW DRAG BOMB	6	3.7	4	4	1.03	
30 DEGREE DIVE BOMB	24	3.9	4	4	.80	
30° HIGH ANGLE STRAFE	21	3.9	4	4	.70	Visible strafe impact beneficial.
45 DEGREE DIVE BOMB	11	3.7	4	3	.79	Difficult to feel release.
45° HIGH ALTITUDE DIVE BOMB	17	3.5	3	3	.80	
60 DEGREE DIVE BOMB	6	3.0	3	3	.63	
LOW LEVEL NAVIGATION	6	3.3	3	3	.52	Limited detail. Simplistic environment.
ARMED RECONNAISSANCE	6	3.3	3	3	.52	Tank too easy to locate.
ATTACK W/FWD AIR CONTROLLER	12	3.8	4	4	.75	Good tactical practice.

TABLE III-1 (Continued)

TASK TITLES	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVI-ATION	PILOT/PROJECT MEMBER REMARK
KEEPING FWD AIR CONTROLLER IN SIGHT	12	3.8	4	4	.85	Limited viewing at long range.
MUTUAL SUPPORT ATTACK	41	3.2	3	3	1.05	
LOCATE TARGET	24	3.7	4	4	.62	Targets too easy to locate. Small targets too hard to differentiate.
IDENTIFY TARGET	24	3.7	4	4	.62	Not enough detail.
ORIENT TO TARGET	24	3.7	4	4	.62	Good FOV.
RESTRICTED PATTERN	20	3.8	4	4	.70	
RANDOM PATTERN	23	4.0	4	4	.64	Restricted due to lack of eighth window.
TERRAIN MASKING PATTERN	10	4.1	4	4	.74	Mountains too austere. Blended background, no texture, no detail.
POP UP PATTERN	42	3.8	4	4	.81	Limited by lack of eighth window.
CURVILINEAR APPROACH	42	3.6	3.5	3	.99	
MOVING TARGET ATTACK	19	3.8	4	4	.83	Too easy to locate when firing.
ORDNANCE ADJUSTMENT	41	3.8	4	4	.89	
REATTACK	24	4.0	4	4	.66	Small targets too hard to see.

TABLE III-1 (Continued)

received high ratings which reflect the systems capability to allow unaltered task performance in these areas. However, performance of low angle events was slightly altered due to the lack of surface detail and texture and the subsequent reliance on the aircraft cockpit instrumentation. It should also be noted that tactical patterns and deliveries received high ratings. The addition of an eighth window in these areas would have been beneficial. Tactical operations were generally too easy to perform in this CIG/Optical Mosaic system due to the austere environment. All tactical tasks could be accomplished; however, target location and identification was easier than in the real-world environment. Mutual support could be accomplished; however, pilots generally had considerable difficulty determining attitude and relative motion of the other aircraft. Compared to air-to-ground tasks, formation was more difficult to perform due to limitations discussed below. Despite some task performance difficulties, two-ship operations were considered a significant strength of this technology. Although night operations received high ratings, the night scene was considered somewhat unrealistic because considerably more cues were available than are available under actual night conditions. It is significant to note the ratings received for aerobatic and airwork tasks. The ratings received for aerobatic and airwork tasks reflect the lack of limitations imposed on these tasks.

(b) Spatial Orientation Cue Analysis

Each task was rated with regard to the spatial orientation cues necessary to perform the task. The sample size and mean ratings are shown in Table III-2. Definitions of each cue is contained in Table II-2. Note that ratings averaged between three (good) and four (very good). As a result of the sample size and limited scale, differences between rating averages are small. They are, however, significant.

The pilots experienced little difficulty in determining their direction, relative location in the environment, and lineup with various environmental features. The dominance of these cues is not necessarily equivalent in the real-world environment due to its more complex nature. The attitude cue received a very good rating. Speed, altitude, and distance cues received lower ratings, probably due to the stylized scene and reduced level of detail, texture, and general scene content.

CUE	SAMPLE QUANTITY	MEAN RATING
ATTITUDE	464	3.847
DIRECTION	400	4.007
SPEED	446	3.495
ALTITUDE	449	3.463
DISTANCE	363	3.446
LOCATION	440	3.932
LINEUP	454	3.969

TABLE III-2 - SPATIAL ORIENTATION CUE RATINGS (CIG/OPTICAL MOSAIC)

CHARACTERISTIC	SAMPLE QUANTITY	MEAN RATING
SIZE	203	3.852
SHAPE	196	3.903
DETAIL	200	3.485
CLARITY	204	3.382
MOVEMENT	168	3.875
POSITION	178	3.882
ENVIRONMENT	199	3.884

TABLE III-3 - SPECIFIC REFERENCE CHARACTERISTICS RATINGS (CIG/OPTICAL MOSAIC)

TOPIC	SAMPLE QUANTITY	MEAN RATING
FOV	212	4.113
IMAGERY ALIGNMENT	60	3.935
IMAGE RESOLUTION	60	3.605
GAMING AREA	--	NOT RATED
VISUAL SCENE ADEQUACY	144	3.521
REAL WORLD COMPLEXITY	24	3.708
METEOROLOGICAL CONDITIONS	22	3.136

TABLE III-4 - ASSOCIATED RATINGS (CIG/OPTICAL MOSAIC)

(c) Specific Reference Characteristic Ratings

Numerous items, objects, and features in the environment were rated in terms of seven characteristics. The characteristics, sample size, and mean rating are shown in Table III-3.

The CIG/Optical Mosaic system evaluated received good to very good ratings in these areas. The pilots felt that the general size and shape of features was proportionally correct. Likewise, they felt that the objects displayed the correct movement or lack of movement, as appropriate. Area features were positioned and blended into the environment quite well. Feature detail, and clarity received a lower rating.

(d) Associated Ratings

Associated topics were rated during the evaluation and appear in Table III-4. Although all areas received generally good ratings, many comments were collected in these areas and are addressed in both the Limitations, Anomalies, and Improvements section and the Significant Strengths section below.

(2) Limitations, Anomalies, and Improvements

The system's limitations and anomalies, as obtained from the pilots, are combined and presented in this section. Each item is explained and followed by a suggested engineering improvement which is subsequently reviewed to determine if the stated shortcoming could be remedied by the proposed improvement. The proposed improvements include an assignment of risk in the categories of low, moderate and high risk (see glossary for definition of risk).

(a) Image Generation

1. Environmental Simplicity

Several objects or features in the visual scene were too easy to locate, thus making some tasks too easy to perform. These items included the run-in lines on the left conventional weaponry range, the airfield, the tank (due to its constant shooting), the conventional range foul line, the grid pattern (as applied to weaponry and aerobatics), the AAA site (due to its constant shooting), the pointed mountains, an out-of-place target (e.g., a black tank in a light field), the night range targets, and the night runway complex. It thus appeared that this type of image generation and display would allow many items such as the above, to be located too easily. The low level navigation task was too easy to perform because the visual scene did not supply enough distractions to task load the pilot (i.e., not enough similar ground detail located in proximity to the navigation checkpoints). The spatial orientation cues of speed, altitude and distance were difficult to determine during the performance of specific tasks such as takeoffs, touch-and-go landings, full stop landings and low level navigation. While performing weapons delivery on tactical targets and flight close to the mountains it was difficult for the pilots to determine distance (slant range).

a. Proposed Technical Improvement

In a monochrome visual system such as this system utilizes, the degree of visual prominence of a feature evolved from the gray shade differential between it and its immediate surrounding. There were 1024 shades of gray (levels of brightness) used in generating the display imagery. Sixty-four increments ranging from black to white were available to model the visual environment; the remaining shades were used for edge smoothing, curved surface shading, fading, limited visibility, and other real-time brightness visual modifications. Due to opposing pilot recommendations, the left and right strafe and skip bomb target areas were modeled in two extremes of prominence as indicated above, but can be modeled to degree of contrast desired between the target and background. Such modifications can be readily accomplished, on-line, visually by observing the gray shade changes dynamically. The only requirement would be to have a concensus of opinion in establishing the image prominence. The environment data bases could be readily generated, modified and amended. The brightness and contrast of the CIG image can be controlled by the modeler and thus represent no risk.

The different levels of target prominence could also be used advantageously during training. For example, during early phases of training the target could be made very noticeable. Then as the student progresses, the target could be made less visible requiring navigation on other ground information.

The constantly shooting tank, constantly shooting AAA, pointed mountains, and out of place target were the result of the short time period to prepare for this evaluation. The constant shooting can be corrected by providing provisions for automatic or manual activation of the shooting. The pointed mountains could be corrected by different modeling techniques and the out of place target could be corrected by more appropriate dynamic position inputs which position the moving target. Correction of these items represent no technical risk.

Further refinement in the operating system software could make the environment features mentioned much less easy to locate visually. However, those features in the environment which in the real world are difficult to locate and identify because they are camouflaged or blend in with a random textured background, would be difficult to simulate by attempting to imitate the real world. This is due to the fact that the present SOA of CIG technology does not allow an infinite amount of detail in the display scene. Another limiting factor is the overall resolution of the display system. In order to provide a wide FOV display with a resolution comparable to the pilot's visual resolution capabilities, a significant increase in system hardware complexity and cost will result. This is not practical nor cost effective with the present SOA technology. Addition of a significant amount of surface texture is not presently within the SOA of CIG technology. However, some texture can be provided by the use of edges, thus reducing the overall image content. Research programs are presently underway to develop algorithms for adding texture and contours to the CIG image without the use of edges. Since this is yet to be developed, texturing is considered a high risk item.

b. Estimate of Proposed Improvements

The real world environment provides a level of scene complexity that creates a certain level of task loading under which recognition and identification tasks are accomplished. It is a design goal of a weapons delivery simulator to create a simulated environment commensurate with a desired task loading. The trainee can then practice and learn eye/hand motor skills and habit patterns under the desired task loading which will enable him to perform optimally in the aircraft under a similar task loaded condition. Based on the experience acquired during this project, it is felt that the simulated environment will require those technical improvements mentioned above (i.e., texturing, point light sources, and modeling improvements) plus the addition of more edges which would be displayed to the pilot and more edge processing capacity to increase the task loading. The increased edges and edge processing capacity will provide more cultural and geographic details that will add further real-world complexity to the environment and thus more closely approach task loading as experienced in actual flight. The exact number of edges required would depend on the optimum blend of texturing and point light sources. However it appears the minimum capability per cockpit would be that demonstrated capability of the subject CIG system (i.e., a minimum of 2500 edges per cockpit). With a more complex environment it is estimated that real-world task performance would be improved. It is recognized however that real-world duplication of a visual scene will be limited because the SOA of CIG technology has finite potential to create real-world environments.

2. Scene Breakup

Some scene breakup was encountered during tactical range operations and formation flight. This condition, when observed, was very distracting.

a. Proposed Technical Improvement

Scene breakup observed during tactical range operations and formation flight was due to two causes. One cause was as a result of CIG Visual System processing capacity overload and the other cause was a result of an error in disk storage of an environment data base model. The capacity overload condition resulted from the fact that the environment data base for tactical range operations and formation flight contained more displayed edges than the system had capacity to process. As processing capacity limits were reached, the system automatically reduced the amount of environment data to be processed by eliminating some models from the environment. This was a design feature which allowed an environment to be viewed even if the environment exceeded the processing capacity of the system. A finite and known processing capacity limitation is inherent in any CIG design. In the process of developing environment data bases, if the processing capacity of the system is exceeded, then the data base must be simplified to keep the processing requirements within the system capacity.

The scene breakup due to the error in the storage of the environmental data base model could easily be avoided by taking more time to dynamically evaluate the data base and correct any errors which exist. This correction represents no risk.

b. Estimate of Proposed Improvement

The proposed technical improvement appears to substantially reduce the impact of scene breakup on task performance. Sizing the edge capacity of the system and allotting the edges more carefully based upon the tasks and cues required for the task should minimize the effects of scene breakup on tactical range operations and formation flight.

3. Night Lighting Conditions

Night airfield and range complexes were not representative of actual night conditions. Both areas appeared in a dusk setting, which was as well defined as the daytime conditions. In addition, the night runway complex was not supported with surrounding lighting, such as a town complex or typical base complex.

a. Proposed Technical Improvement

The night conditions were unnaturally bright due to unwanted reflections (also called ghosts) in the display optics. By keeping the background a little brighter than black, these reflections would not be as noticeable. This is an inherent problem with this type of display optics. Neglecting the display problem, the night conditions could be modeled, within the CIG System limitations, to provide any desired degree of scene detail. The content of the night environment and the contrast between features of that environment could be easily modified by changing the environmental data base.

A very large increase in the number of lights visible in the environment would require additional special light processing capacity. This represents no technical risk since off-the-shelf systems include this feature as an option.

b. Estimate of Proposed Improvement

The proposed improvement indicates that true night scenes are not possible with the pancake window display and that moonlight night conditions are the optimum for the system. However, with careful modeling, it appears that the correct amount of ground cues could be provided.

The increase in night lighting to provide a more realistic air base environment appears feasible.

4. Visibility Restrictions

Although the systems capability to create inflight visibility restrictions was excellent, the actual inflight distance appeared to be less than selected (e.g., a 40,000 foot selection appeared to generate approximately an 18,000 foot visibility restriction).

a. Proposed Technical Improvement

This CIG System used gradual shading changes to show the effect of reducing visibility. The computer read the digit wheel settings at the instructor console to determine the distance that an object should no longer be seen. According to original specifications, this was defined as two percent of the original shade of the object. The shading was reduced in an exponential manner to arrive at this two percent shade at the distance specified at the instructor console. In future systems, it would be advisable to use a different fade out specification. The correction to this problem is considered no risk.

b. Estimate of Proposed Improvement

It is estimated that an optimized shading could be achieved and could significantly reduce or eliminate this anomaly.

5. Scene Movement

A limited amount of scene movement was noticed on the conventional gunnery range and in the general grid pattern environment, which created a small degree of pilot disorientation.

a. Proposed Technical Improvement

The small amount of scene movement was due to vertical quantization. One of the visual effects of vertical quantization is that nearly all horizontal edges tend to jump from one scan line to the next rather than move continuously. When the surface plane pattern is viewed at long ranges, the pattern faces change size as a function of the front and back edges jumping scan lines. This changing pattern size appears to the viewer as a small vertical movement of the surface plane. To correct this visual effect, vertical smoothing is required. Current CIG systems use both horizontal and vertical edge smoothing (the system evaluated has only horizontal) to reduce the quantization effects. Quantization is inherent in CIG systems since the image is digitally quantified during processing. The use of horizontal and vertical edge smoothing reduces the visual effects of this quantization but does not completely eliminate the visual effects of quantization. It is considered low risk to reduce these effects, but high risk to completely eliminate these visual effects.

b. Estimate of Proposed Improvement

The addition of vertical edge smoothing will reduce this anomaly.

6. SAM Dynamics

Although SAM simulation was judged to be outstanding, there were several SAM characteristics which require modification. The SAM appeared to be too large, had instant guidance, and had unrealistic launch and tracking dynamics.

a. Proposed Technical Discussion

The purpose of the SAM simulation was to demonstrate this CIG capability. A more faithful simulation with better missile dynamics is considered to be no risk.

b. Estimate of Proposed Improvement

A SAM simulation suitable for training can be provided.

7. Environment Size

The overall environment was not large enough to allow unaltered performance of some aerobatic maneuvers. A lack of point references on the horizon also hindered aerobatic tasking (e.g., barrel roll, cloverleaf).

a. Proposed Technical Improvement

The environmental data for this project was not designed to provide cues for aerobatics. A data base with a square gaming area (500 NM on a side) with mountains on the horizon for point references exists but was not used for this evaluation. A very large gaming area with mountains on the horizon for point references could be modeled. Therefore, this deficiency can be corrected at no risk.

b. Estimate of Proposed Improvement

The proposed correction appears to provide the solution to the environment size and point reference problems encountered during the performance of aerobatic maneuvers.

8. Other Aircraft Recognition

The lead aircraft was displayed in three major levels of detail. The most austere aircraft did not provide enough detail for the pilot to judge closure rate and obtain the proper positioning cues. The most detailed aircraft offered more detail than was necessary for formation flight. The aircraft which was modeled between these two extremes did not have the desired reference points to use for proper positioning, but did provide an adequate amount of detail for use in judging closure rate. An ideal model would incorporate the best features of all observed.

In addition, it was very difficult to determine the lead aircraft's attitude and relative motion beyond a range of approximately 2500 feet. Thus, tactical formation and mutual support tasks were difficult to perform.

a. Proposed Technical Improvement

The lead aircraft could be modeled with the appropriate detail at no risk. The cause of the problem with judging closure rate is not known. It is a suggested future research topic and the risk of this factor is unknown.

The difficulty in seeing the lead aircraft at a range of 2500 feet or beyond was due to the resolution of the display system. The lead aircraft subtended an angle equal to about the limiting resolution of the display system at 2500 feet. This limitation could be overcome by increasing the display resolution. Another approach would be to present the display image size of the lead aircraft independent of the range to the aircraft. This feature is included in the system and further evaluation is required. The technology for providing a wide-angle display with high resolution imagery throughout is not currently available and is considered high risk.

b. Estimate of Proposed Improvement

It appears that appropriate specification of the references and detail required for the lead aircraft will provide the basic formation references required for spacing out to approximately 2000-2500 feet.

The degradation of the lead aircraft outside approximately 2500 feet as a result of the resolution of this particular display is a limitation for formation rejoins, mutual support, tasks, and any air-to-air tasks. The proposed solution of controlling the size of the display image independently of the range did not appear to be a satisfactory solution during the project. Consequently, there does not appear to be a ready solution to the degradation of the lead aircraft image. Correction to limitations in these areas is considered high risk.

c. Additional Discussion

The key to maintenance of target aircraft image quality at long ranges lies in the use of a shrunken raster (dual raster) display system. Use of such a system dictates a display scanning scheme where available scan writing time is shared between target aircraft and background images. The current resolution and brightness of the CIG/Optical Mosaic display are dependent on the single raster display scanning standard used. Adaption of the dual raster display for integrated background/shrunken raster aircraft target operation would result in a significant degradation in the background image quality as currently presented by the CIG/Optical Mosaic system. Development and use of improved deflections electronics (two years, moderate risk) to implement fast retrace dual raster display scanning would minimize degradation of the background image quality; however, background image quality would still be significantly inferior to that currently displayed.

The display resolution limitation represents a significant system design problem which requires careful detailed analysis before a recommended overall system approach can be made.

9. Moving Model

Only one moving object could be displayed at one time. Generation and display of multiple moving models would be advantageous.

a. Proposed Technical Improvement

Multiple moving models can easily be generated and displayed by CIG Systems. However, if a large number of moving models are required, a significant amount of General Purpose Computer (in the simulator or CIG) processing time will be required to generate the dynamic data required to control the movement of the moving models. This addition is considered low risk.

b. Estimate of Proposed Improvement

The ability to generate and display multiple moving models will increase tactical complexity to a level found in very few places outside actual combat.

(b) Image Display

1. Field of View

Although the displayed FOV was considered excellent for nearly all phases of flight, an additional window directly above and behind the pilot would facilitate observing ordnance impact, monitoring and defeating SAM attacks, and properly monitoring target location when employing random tactics.

a. Proposed Technical Improvement

Adding the eighth display window above the pilot would be possible since other SOA simulators use the eighth channel. There is no technical risk involved.

b. Estimate of Proposed Improvement

Addition of the eighth window would completely remedy this limitation.

2. Lead Aircraft Distortion

During formation flight, the wings on the lead aircraft appear to bend as they transited a channel seam.

a. Proposed Technical Improvement

Apparent bending of the lead aircraft wings as the wing transitions across the adjacent channels was probably due to a slight distortion in the TV rasters and optics of the adjacent channels. While some improvements could be incorporated to reduce or eliminate the distortion, a completely distortion free display is not only impractical but extremely expensive. The general procedure used to achieve best performance is to identify those areas of the display which are more critical and optimize the display performance for those areas by making the necessary compromise adjustments in the display which favor the critical areas. Correction of this deficiency is considered to be moderate risk.

b. Estimate of Proposed Improvement

Apparent bending will continue to be a minor limitation in a mosaic display, especially at close ranges.

3. Window Junctions

The normal fingertip position places the lead aircraft at the junction of three windows (numbers 1, 2, and 4 when on the right side of the aircraft), creating an overload condition, which caused portions of the lead aircraft to break up and disappear.

a. Proposed Technical Improvement

The overload condition which occurs when the lead aircraft is simultaneously visible in several display windows is a result of the fact that the edge processing capacity of the system is not sufficient. It is possible to reduce the complexity of the lead aircraft model such that the system processing capacity is not exceeded. This correction would be low risk.

b. Estimate of Proposed Improvement

Increasing the edge processing capacity and/or reducing the aircraft's complexity (as discussed in item 8, P. III-19) would eliminate the problem.

4. Window Seams

It was distracting to lose a detail which was critical to flight as the image transitted a window seam. For example, the strafe target when viewed throughout the delivery roll-in.

a. Proposed Technical Improvement

In mosaicked displays an interface will exist between adjacent channels, either mechanical or optical, in which a perceptible discontinuity will exist. The intended use of the simulator will have to be considered in the display design such that critical areas of the display will not include adjacent channel interfaces or seams. This was accomplished for this system's visual display considering only the Undergraduate Pilot Training mission and not air-to-ground weapons delivery mission. A more optimum display could be designed for the air-to-ground weapons delivery mission. However, some compromises will have to be made regardless of the mission for which a simulator display is to be optimized. Risk is low, assuming a compromise will be possible.

b. Estimate of Proposed Improvement

The problem will be partially solved in a system optimized for air-to-ground weapons delivery, however, seaming at channel interface is inherent in a mosaic display and will continue to produce slight alterations to task performance.

5. Item Definition

At long ranges small targets (i.e., truck, strafe panel, etc.) were more difficult to locate and identify in the simulator than in the real world due to their indistinctness.

a. Proposed Technical Improvement

This limitation was caused by the system's display resolution. There are concepts for improving display resolution (such as more scan lines, smaller channels, and other methods of target insertion) which are unproven and are considered a high risk. One other alternative is available through data base modification. Since three levels of detail are available for each feature, the level of detail observed at the most distant ranges could be modeled to have a greater contrast and/or be somewhat larger than its actual size. Then as the range to the target is reduced, other levels of detail would reduce the contrast and/or size to more realistic conditions. It is considered to be no risk to implement this feature and low risk to provide visual cues in this manner; however, how this non-real feature would effect training utility is unknown.

The problem of seeing small targets at long ranges is similar to the problem of seeing the lead aircraft at long ranges. Correction of this limitation is also high risk.

b. Estimate of Proposed Improvement

These limitations will be difficult to alleviate.

(c) Associated Simulator Features

1. Motion Platform

The motion system appeared to lag behind that expected as a result of the changes in the visual scene. Additionally, the washout cues appeared to be exaggerated and retarded. These problems indicated that the motion was not syncronized or updated at a rate that is compatible with formation flight or fine tracking tasks.

a. Proposed Technical Improvement

Motion system software commanded outputs, although approximately synchronized with visual outputs, do not manifest themselves to the pilot until later. The result is lag perceived by the pilot. Elimination of response lag is no risk, although a higher cost option (computer processing).

b. Estimate of Proposed Improvement

It is estimated that the improvement should significantly reduce or eliminate this problem.

2. G-Seat

The G-seat did not appear to offer true positive or negative G cues. The seat inflation seemed unnatural and excessive. As a result, the pilots were unable to control their G scheduling using real-time kinesthetic cues.

a. Proposed Technical Improvement

No technical (hardware) improvements are required. However, the normal air-to-ground G-loading regime differs from the normal T-37 training regime. The G-seat algorithms should be modified to present cues specifically structured for the air-to-ground task. This is a low risk area. Future systems that are designed for air-to-ground simulation could include a G-seat with more realistic cues and is considered a low risk item.

b. Estimate of Proposed Improvement

Algorithm optimization may reduce or eliminate the problem.

3. Cockpit Gunsight

The sight lineup appeared to vary between and during missions. When discovered, this situation was readily corrected; however, some means of early detection (manual or automatic) should be identified.

a. Proposed Technical Improvement

Gunsight alignment was found to be affected anytime the simulator was flown in excess of the critical mach number or if it had crashed as a result of over-g or ground impact. This apparently biased CIG ground position extrapolation computations and appeared to misalign the sight reticle with the actual path of the bullets (maximum error was 10 mils.) An initialization point was created with the sight aligned with the strafe target, providing a manual alignment check. This check could be programmed to occur automatically following crash or over-speed conditions. This is considered to represent no risk.

b. Estimate of Proposed Improvement

The problem appears to be completely correctable with the proposed improvement.

(3) Significant Strengths

This section highlights the significant strengths of the CIG/Optical Mosaic system evaluated and complements the earlier section containing demonstrated capabilities.

(a) Moving Object

The capability to display a moving object is considered an outstanding feature of this technology. When the moving object was displayed as a tank, the tank's change in speed and direction of movement necessitated pilot modification of his attack plan based on his estimate of the tank's position at weapon impact. When displayed as a SAM which guided after launch, it forced the pilot to consider target defenses as well as target destruction. Though SAM guidance was simple, and AAA somewhat unrealistic, proper detection and evasion techniques were necessary.

(b) FOV

The large FOV, with usable imagery throughout, provided continuous pilot orientation and allowed most tasks to be performed with little modification. For example, while positioning for a reattack, the pilot was able to keep the target in sight. A slight drawback, however, was the lack of a window above and aft of the pilot which would have allowed for more natural roll-in, SAM avoidance, and air-scoring of weapon impact.

(c) Weapon Scoring

Bomb and strafe scoring appeared to be extremely accurate and correlated very well with pilot error analysis. The real-time console display of release parameters and weapons score, which could be easily interpreted, was very beneficial.

(d) Checkerboard Terrain

The checkerboard terrain, in addition to aiding altitude and range estimation, provided a cue for rate and an approximation of heading change. Combined and correlated with cultural and natural features, the checkerboard terrain, although not large enough, made area orientation and alignment very easy. The well-defined and continuous horizon also made attitude orientation easy.

(e) Visual Display of Weapon Impact

The visual display of weapon impact allowed air-scoring, which is a normal inflight procedure, and provided excellent pilot feedback.

(f) Image Clarity

Contrast and definition were generally good, facilitating target detection and identification. In many cases, however, due to high contrast and lack of detail, targets were too easily detected and identified.

(g) Tactical Operations

The tactical environment allowed realistic performance of tactical tasks, including terrain masking, a moving target attack, and restricted run-in attacks. With imagery throughout the FOV, tactical deliveries could be made with unlimited dive angles and from all axes of attack. The stark environment, however, which was low in detail due to the limited number of edges available, limited target complexity.

(h) Night Weather GCA

Simulated night weather GCAs to weather minimums where visual references appeared in a realistic sequence (flashing strobe lights, runway lighting, then runway environment) were considered extremely realistic.

(i) Flexibility

The inherent flexibility of CIG environmental data bases is considered to be a significant advantage. A potentially unlimited number of environments which are easily amended and modified are available to meet mission requirements and can be rapidly interchanged.

(4) Required/Optimized System Performance Characteristics and Potential Capabilities (CIG/Optical Mosaic)

This section combines the demonstrated capabilities, significant strengths, and proposed technical improvements into an optimized CIG/Optical Mosaic display system. It is important to remember that this optimized system is a departure from the system evaluated and is not based upon the data collected during Phase II. Characteristics included in this section are not all inclusive, nor are they intended to be but are included to provide the reader general understanding of what the authors consider essential in an optimized system using CIG and an Optical Mosaic display.

(a) Required/Optimized Computer Image Generation System Performance

1. Day/Dusk/Night Lighting Capability

The lighting conditions must be sufficiently realistic to provide the correct quantity of visual cues and properly task load the pilot so that his performance of the task in the simulator accurately reflects his performance of the task in the aircraft for the condition simulated.

2. Image Generator Channels

A sufficient number of channels must be provided to input imagery to each channel of a display that approximates the FOV of the aircraft to be simulated. Realistic target migration within the FOV is essential if continuous parameter adjustments are to be made throughout task performance.

3. Edges and Levels of Detail

A significant increase in the number of displayed edges per cockpit beyond the 2000 edges (2500 with overload) demonstrated is required to provide the environmental detail necessary to allow unaltered task performance, especially for tactical operations. The increased number of edges would prevent scene breakup due to system overload, allow sufficient and more realistic modeling to provide a confusion factor (i.e., correct target identification) in the target area. This confusion factor is especially important in tactical target areas where reduced contrast ratios, camouflage, item similarity, and high stress are competing factors.

An increase in the number of levels of detail to provide smoother transitions between levels will eliminate the distractions and false cues from abrupt level changes.

The use of curved surface shading, the concentration of edges within the data base, and the development of texturing and contouring algorithms should be used to allow for more efficient use of the available edges to improve the modeling capability of a given system.

4. Curved Surface Shading

Curved surface shading is required to allow the CIG system to present solid curved surfaces using edges to generate the surface. Curved surface shading also provides more realistic modeling of real-world objects which are not constructed of only flat surfaces. This permits CIG to present more realistic cues for task performance. The technique is especially important for constructing aircraft for formation tasks and ground vertical relief.

5. Surface Texturing

Surface texturing is required to provide velocity cues during low angle/low altitude tasks. These cues are especially important during low angle weapons delivery (e.g., 10°-15° low angle bomb, low angle strafe) and are used to determine the proper release point, prevent ground contact, determine ground track, and provide additional flight path and speed cues.

Current technology can only provide these cues through the use of edges (very inefficient) or the use of surface shading. Point lights (colored black) have been demonstrated and provide a minimal level of texturing.

Research and development is required to develop the algorithms to efficiently provide sufficient surface texturing required for proper low angle/low altitude task accomplishment.

6. Point Light Sources

Point light sources are required to simulate the night lighting around an air field, urban development and rural light area. Generation of point lights must not be at the sacrifice of edges; they must be a separate and distinct feature. The light points must be functional with respect to brightness, directionality, range and color/shades of gray.

7. Multiple Moving Models

Multiple moving models that can be simultaneously displayed are required. These would include vehicles, surface-to-air and air-to-surface missiles, and aircraft. These models will allow attacks on moving targets, defensive maneuvers against missiles, formation flight training, mutually supporting ground attack, and FAC operations.

8. Weapons Effects and Scoring

Weapons effects, including ordnance impacts, tracer fire, and target destruction are required to provide visual feedback to the pilot to indicate the effectiveness of his weapons delivery and to allow error analysis prior to the next delivery. This is especially important on the tactical range or for targets of opportunity where the target may not be designated for score.

Accurate weapons trajectory and scoring algorithms are required to properly compute and display weapons effects. Weapons trajectory and scoring computations are normally performed in the host simulator computer, not the visual computer, but they form an essential part of any weapons delivery simulation.

9. Weather Effects

The ability to vary ceiling and visibility realistically is required to restrict the envelope around the target in which the pilot may maneuver his aircraft and still see the target. These restrictions substantially increase the task loading on the pilot during tactical weapons deliveries to better approximate inflight task performance. This feature is particularly important for A-10 aircraft simulation.

(b) Required/Optimized Optical Mosaic Display System Performance

1. Field of View

The FOV of the display, considering head movement, must closely match that of the aircraft to be simulated in order to allow the target to migrate within the FOV as in the aircraft. This is essential to prevent abnormal task performance. Normal aircraft visual restrictions such as canopy frames and aircraft surfaces are essential. Some of the tasks requiring the full FOV include air scoring, SAM evasion, recovery from a weapons delivery, normal target placement, high and low angle bomb, strafe, tactical weapons deliveries, and reattacks on tactical targets.

2. Displayed Imagery

The display system must be capable of displaying CIG imagery throughout the FOV except where occulted by aircraft structure. The full FOV displayed imagery allows normal orientation and provides supporting and peripheral cues for all tasks.

3. Display Orientation

Optimum display configuration and display orientation is essential for each aircraft type. This optimization is essential to maximize the usable FOV and to keep window joints and tri-joints from distorting critical cue areas (e.g., the high 10 o'clock position where a target is placed during a curvilinear weapons delivery).

4. Displayed Image Discontinuity

Images displayed dynamically must be closely aligned and exhibit minimal discontinuity when tracking across window joints or tri-joints to assure task continuity during tasks performance. Low angle strafe on a controlled range where continuous alignment and position judgments are required during normal roll-in and curvilinear patterns is especially critical.

Some additional development may be required in this area to minimize discontinuity in display window joints.

5. Displayed Image Resolution

Displayed image resolution must be optimized to the maximum extent possible. Resolution on the order of 6 to 7 arc minutes is state of the art with present single raster displays and is sufficient for most air-to-ground tasks. Improvements in resolution as a result of on-going engineering efforts should be incorporated. Judicious use of contrast and changing the target size/range relationship can be used to improve the visibility of small targets at longer ranges. These special features must not be visually evident to the pilot and must not affect reticle or pipper matching cues which serve as range cues.

Additional research and/or engineering development is required to provide single raster displays with the resolution required (1-2 arc minutes) to realistically display small ground and/or airborne targets without the use of special effects.

6. Color

Monochrome display on mosaicked CRTs has been successfully demonstrated and evaluated. Scene content, with improvements to the generation system as previously outlined, will overcome many of the limitations in this evaluation. Additional limitations can be overcome through the use of color displays. Results from the 2B35 evaluation indicate that color improves the "apparent resolution", that is, allows speedier and more accurate identification of ground or airborne objects, at apparently increased ranges, and yields better low altitude and speed cues. Color makes task loading more realistic by reducing the requirement for pilot concentration on a specific feature. Targets are recognized more naturally by their color contrast and appearance in the overall scene. This enables the pilot to spend more time assessing other cues and making smaller corrections to aircraft orientation rather than concentrating on the target (object) itself. However, all pilots indicated that color was not a suitable substitute for enriched environments.

Research and development in color image input devices to the infinity optics is essential.

7. Display Reflections

Optimization of the display optics to eliminate unwanted reflections (ghosts) is required. While not a significant problem, some anomalies occurred during night conditions. Due to the concern for ghosting, the display brightness was set too high for night conditions. The problem was detected with the CIG/Optical Mosaic system, however, it was not apparent in the TMB/Optical Mosaic system.

2. TMB/DOME PROJECTION RESULTS

a. Technical Results

(1) Visual System Features

(a) Ground Terrain Display Format

The system displayed an AOI in a 36° X 48° rectangular format.

(b) AOI Slew

The FOV of this device was ± 133° horizontal, 108° vertical (-8° over the nose and -45° over the side), and was limited primarily by cockpit gimballing on the motion system and by the projection system location and configuration.

The terrain image could be displayed to the pilot in three ways. The first was to fix the AOI to the x-axis of the aircraft. The terrain image within the AOI would then move solely as a function of the orientation of the aircraft. A second method was to fix the AOI to a specific predetermined target. With this method the visual probe pointed at the target at all times and the image was displayed on the dome in the properly oriented position. The third method was to position the probe over the terrain based on the pilot's viewing angle and the location of aircraft. The image displayed was therefore a function of aircraft location, aircraft attitude, and the pilot's head position.

The projection screen in the device evaluated consisted of a display screen which was 266° in azimuth (± 133°) and ± 108° down to the cockpit cut-off angle in elevation (Nose -8°). However, when the pilot looked over the side, this lower limit exceeded -45°. During the headslaved visual portion of 2235, software limits were placed at +85° and -45° in target projector elevation. At these points the edges of the image began to be obscured by the sky/earth projector near the upper limit and to see below -45° the pilot's head was outside the boundary of the cockpit canopy.

(c) Concurrent Display

This system was capable of displaying concurrently a ground AOI, the image of another aircraft, a fixed reticle gunsight, and background terrain surrounding the AOI. The other aircraft image would be computer generated and inset into the AOI. Detail of the CGI would be limited to 32 surfaces. Software for this image was still being refined for combination with the head-slaved AOI, consequently, it was not demonstrated for Project 2235. The background terrain was relatively undetailed.

(d) Mission Monitoring

Monitors were located at the control console to display the AOI and the view from an over-the-shoulder camera in the cockpit. Flight parameters and flight instrument data were continuously displayed on a CRT. Additionally, various data were recorded on strip charts, off-line hard copy printouts, and on magnetic tape.

(e) Weapon Delivery Scoring

The system had a limited special effects capability to display missile firings and impact. This was not demonstrated for Project 2235. All weapon delivery parameters and scores were presented on the CRT display and on a hardcopy printout. The strafe score was represented by the distance and azimuth from the target of the last round fired. All mission data was recorded on magnetic tape for later off-line, hardcopy printout and analysis.

(f) Varying Ceiling and Visibility Conditions

A sky plate mounted in the model board camera probe was capable of simulating variable ceiling conditions (0-3000 feet on the 1500:1 board and 0-20000 feet on the 5000:1 board). The same sky plate could be used to simulate variable visibility.

(g) Moving Targets

Capability existed to inset one or more computer generated moving targets. Detail would be limited to 32 total surfaces. The capability was not adequately demonstrated.

(2) Technical Performance Measurements

(a) Display Resolution

No specific test was made for resolution, but the MTF curves (reference Volume 2, Figures I-4 through I-11), indicate a limiting resolution of from five to six arc minutes per TV line over most of the AOI. Limiting display resolution was about four arc minutes at AOI center with the AOI projected 90° right.

(b) Scene Detail

No quantitative figure can be applied to the amount of scene detail in the model board image.

(c) Contrast

AOI highlight brightness measured approximately half a foot lambert. Terrain background from the sky-earth projector measured over a tenth of a foot lambert. Thus, contrast is limited to, at best, about five. On the gray scale tests, there was some difficulty in visually discriminating between adjacent steps at both the black and white ends of the scale.

(d) Brightness

The image from the sky-earth projector averaged about .18 foot lambert for the sky, .12 foot lambert for the earth, and .35 foot lambert above the horizon. AOI highlight brightness ranged from .48 to .56 foot lambert depending on AOI position and sampled location within the AOI. This range is essentially a constant when one considers measurement techniques and the logarithmic response of the human eye.

(e) MTF

Static horizontal modulation transfer averaged about 35% at 10 arc minutes at the center of the AOI and about 30% at the corners. There was a broad spread in the readings for modulation transfer, not all of which should be attributed to the quality of the display. At first, it was thought that some brightness variation was being caused by variations in probe pitch, but a later test showed that image brightness was essentially constant over the full range of the pitch mirror. Some variation appeared to have been caused by the difference in frame rates between our observer camera and the display. The largest variation, however, seemed to have been caused by uneven brightness of the light box. The box had been checked earlier but with the photometer about 10 feet away. For our modulation transfer measurements, the probe sometimes came within 18 inches of the box. From this distance, the perspective is such that the edges and corners of the light box are considerably less bright than the center. Modulation transfer decreases under dynamic conditions. Any probe movement in excess of about 10° per second produces appreciable loss of detail. The readings for dynamic modulation transfer should not have been affected by the above mentioned light box variations since they were all taken at zero pitch from the center of the light box.

(f) AOI Edge and Corner Resolution

Display modulation transfer at ten arc minutes is about 10-15% less in the corners of the AOI than in the center. The difference when looking at the whole system from model board camera to display was less conclusive. It did appear that there was a greater loss of vertical modulation transfer in the corners than there was horizontal.

(g) Image Distortion

It should be noted that when a ratio 3 X 4 rectangle is viewed with a 60° diagonal field of view, the vertical centerline subtends an angle of 38.21 degrees at the eyepoint. The horizontal centerline subtends an angle of 49.58 degrees at the eyepoint. Also, equal intervals along either centerline will not subtend equal angles at the eyepoint. The angular subtense of a segment of either centerline will be reduced by the square of the cosine of the viewing angle relative to an equal segment at the center of the rectangle. Ideally these angles should all be preserved in the image presented to the pilot. The demonstrated AOI was projected on a 36 X 48 degree format in such a way that equal line segments in an original 3 X 4 rectangular grid were mapped approximately as equal angles in the display. Table III-5 is a comparison of viewing angles along the vertical and horizontal centerlines of a 22 segment by 22 segment grid for true perspective and for equal-angle mapping.

(h) Variation of Brightness

With the AOI projected forward and with a 50% APL flat field displayed, there was essentially no

Point	Vertical Centerline True	Equal Angle	Horizontal Centerline True	Equal Angle
Center	0°	0°	0°	0°
1	1.80°	1.64°	2.40°	2.18°
2	3.60°	3.27°	4.80°	4.36°
3	5.40°	4.91°	7.18°	6.55°
4	7.18°	6.55°	9.53°	8.73°
5	8.95°	8.18°	11.86°	10.91°
6	10.70°	9.82°	14.14°	13.09°
7	12.43°	11.45°	16.38°	15.27°
8	14.14°	13.09°	18.57°	17.45°
9	15.82°	14.73°	20.70°	19.64°
10	17.48°	16.36°	22.78°	21.82°
11	19.11°	18.00°	24.79°	24.00°

One of the effects of displaying the grid with equal-angle mapping is to make objects at the center of the AOI appear 9% too far away. [(1.80-1.64)/1.80 = .089]

The following is a summary of elevation and azimuth errors for the LAMARS AOI relative to the equal-angle values above:

AOI	Area	ERROR Mean	Maximum	Location of Max Error
Forward	all	.24°	.90°	left edge
Forward	center 18° X 24°	.22°	.56°	upper right
90° right	all	.72°	2.02°	right edge
90° right	center 18° X 24°	.60°	1.09°	right edge
90° right	left half	.42°	1.22°	top edge
90° right	right half	1.11°	2.02°	right edge

Summary relative to true perspective:

AOI	Area	ERROR Mean	Max	Location of Max Error
Forward	all	.95°	1.46°	top edge
Forward	center 18° X 24°	.94°	1.17°	lower right
90° right	all	1.61°	3.08°	right edge
90° right	center 18° X 24°	1.34°	2.04°	right edge
90° right	left half	1.28°	2.63°	top edge
90° right	right half	2.05°	3.08°	right edge

The AOI had a pronounced keystone effect when projected 90° right. The left edge subtended a vertical angle of 37.45° while the right edge subtended a vertical angle of 31.58°.

TABLE III-5 - AOI DISTORTION MAPPING (TMB/DOME PROJECTION) shading in the AOI (.22 to .24 foot lamberts for six data points). When projected 90° right, the display was slightly brighter but still had no objectionable shading (.23 to .30 foot lamberts).

(i) Collimation Errors

Not applicable.

b. Operational Results

The results of the TMB/Dome Projection system evaluated are discussed under the following three headings: (1) Demonstrated Capabilities and Average Ratings; (2) Limitations, Anomalies, and Improvements; (3) Significant Strengths. A final section is included, (4) Optimized System Characteristics and Potential Capabilities, which is used to introduce a theoretically optimized system using TMB/Dome Projection.

(1) Demonstrated Capabilities and Average Ratings

Ratings and comments are listed in this section.

(a) Task Accomplishment and Ratings

The 81 tasks which were performed during the Phase II evaluation are listed in Table III-6. The pilots were asked to rate each task with regards to the capability of the device to allow performance of the task.

The task ratings for the TMB/Dome Projection system were low in many areas and 22 of the 81 project tasks could not be accomplished due to system limitations and anomalies. The performance of takeoff, departure, approach and landing tasks was possible with this technology with some alterations from normal performance due to the small, head-slaved AOI. Visual navigation tasking was also possible in this device, although somewhat rushed due to the limited size of the gaming area.

Weaponry patterns, roll-ins, and recoveries were possible in this device. Low-level bomb was not accomplished due to the probe protection system's minimum altitude feature. High angle dive bomb was restricted by the pitch limit on the probe. All

TASK TITLES	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVIATION	PILOT/PROJECT MEMBER REMARKS
TAKEOFF	16	3.2	3	3	.66	
NIGHT TAKEOFF	11	2.8	3	3	.60	
DEPARTURE	10	3.0	3	3	.67	
NIGHT DEPARTURE	12	2.3	2.5	3	.87	
STRAIGHT IN	6	3.2	3.5	4	.98	Unnatural head movement required.
NIGHT STRAIGHT IN	6	3.2	3	3	.75	
RADAR FINAL APPROACH	0	NOT ACCOMPLISHED - NO MONITOR CAPABILITY				
VTR OVERHEAD	16	2.3	2.5	3	.79	Position and altitude cues difficult.
NIGHT VFR OVERHEAD	10	2.0	2	2	.82	Runway lighting caused problem.
GLIDE PATH CONTROL	11	2.7	3	3	.90	Uncomfortable head position required.
NIGHT GLIDE PATH CONTROL	12	2.4	3	3	1.00	
GO AROUND	17	2.9	3	3	.70	Altitude and location cues difficult.
NIGHT GO AROUND	12	2.3	2.5	3	.87	
CLOSED	15	2.5	2	2	.83	Lack of visual cues to aid orientation.
NIGHT CLOSED	10	2.0	2	2	.82	
REENTRY	16	2.9	3	3	.85	Locating airfield very difficult.
NIGHT REENTRY	16	2.4	2.5	3	.96	Locating airfield difficult.
LOW APPROACH	11	3.0	3	3	.77	Unnatural head movement required.
NIGHT LOW APPROACH	6	2.8	3	3	.41	Unnatural head movement required.
TOUCH AND GO LANDING	11	2.8	3	3	.60	
NIGHT TOUCH & GO LANDING	6	3.2	3	3	.75	Uni-directional runway light.
FULL STOP LANDING	11	2.8	3	3	.60	
NIGHT FULL STOP LANDING	6	3.2	3	3	.75	
LAZY EIGHT	6	2.5	2.5	2,3	.55	Attitude cues difficult.
CHANDELLE	6	2.7	3	3	.52	Lack of references outside of AOI.
SLOW FLIGHT	6	3.0	3	3	1.10	
STALLS	5	2.8	3	4	1.30	
VERTICAL RECOVERY	0	NOT ACCOMPLISHED - PITCH LIMIT ON PROBE				
SPINS	0	NOT ACCOMPLISHED - NO APPROPRIATE FLIGHT DYNAMICS				
AILERON ROLL	6	3.3	3	3	.52	
BARREL ROLL	6	3.2	3	3	.75	Insufficient horizon line cues.
CLOVERLEAF	0	NOT ACCOMPLISHED - PITCH LIMIT ON PROBE				
LOOP	0	NOT ACCOMPLISHED - PITCH LIMIT ON PROBE				
IMMELMANN	0	NOT ACCOMPLISHED - PITCH LIMIT ON PROBE				
SPLIT S	0	NOT ACCOMPLISHED - PITCH LIMIT ON PROBE				
CUBAN 8	0	NOT ACCOMPLISHED - PITCH LIMIT ON PROBE				

TABLE III-6 - TASK ACCOMPLISHMENT AND RATINGS (TMB/DOME PROJECTION)

TASK TITLES	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVI- TION	PILOT/PROJECT MEMBER REMARKS
FORMATION TAKEOFF	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
CLOSE FORMATION	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
ROUTE FORMATION	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
CROSS UNDER	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
CLOSE TRAIL	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
EXTENDED TRAIL	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
TACTICAL FORMATION	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
FORMATION LANDING	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
BOX PATTERN	34	3.0	3	3	.76	AOI size and control.
NIGHT BOX PATTERN	5	2.2	2	2,3	.84	Sparse lighting.
ROLL IN	36	2.7	3	2	.86	AOI size and control pitch limit.
NIGHT ROLL IN	6	2.5	3	3	.84	Sparse lighting.
DIVE ANGLE ESTABLISHMENT	36	2.9	3	3	.64	Easier during target slaved.
NIGHT DIVE ANGLE ESTA- BLISHMENT	6	2.5	3	3	.84	
RECOVERY	36	3.5	3	3	.51	Horizon discontinuity.
NIGHT RECOVERY	6	2.7	3	3	.82	
LOW LEVEL BOMB	0	NOT ACCOMPLISHED - MINIMUM ALTITUDE LIMIT ON PROBE				
LOW ANGLE STRAFE	30	3.0	3	3	.74	
NIGHT LOW ANGLE STRAFE	6	2.2	2	2	.75	
10 DEGREE SKIP BOMB	29	3.3	3	4	.76	Restrictive altitude limit.
15 DEGREE LOW ANGLE BOMB	35	3.2	3	3,4	.76	
NIGHT 15 DEGREE LOW ANGLE BOMB	6	2.3	2.5	3	.82	Unnatural head movement.
20 DEGREE LOW ANGLE LOW DRAG BOMB	30	2.5	3	3	1.11	Maximum altitude restriction
NIGHT 20 DEGREE LOW ANGLE LOW DRAG BOMB	6	1.3	1	1	.82	
30 DEGREE DIVE BOMB	30	3.0	3	3	.81	
30 DEGREE HIGH ANGLE STRAFE	24	2.8	3	3	.90	
45 DEGREE DIVE BOMB	24	1.8	2	2	.76	Probe pitch limit restriction.
45 DEGREE HIGH ALTITUDE DIVE BOMB	24	1.6	2	1,2	.65	Probe pitch limit restriction.
60 DEGREE DIVE BOMB	0	NOT ACCOMPLISHED - PITCH LIMIT ON PROBE				
LOW LEVEL NAVIGATION	6	2.3	2.5	3	.82	Minimum altitude restriction.

TABLE III-6 (CONTINUED)

TASK TITLES	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVIATION	PILOT/PROJECT MEMBER REMARKS
LOW LEVEL NAVIGATION	6	2.3	2.5	3	.82	Minimum altitude restriction.
ARMED RECONNAISSANCE	6	2.8	2.5	2	.98	Small AOI and restricted altitude.
ATTACK WITH FORWARD AIR CONTROLLER	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
KEEPING FORWARD AIR CONTROLLER IN SIGHT	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
MUTUAL SUPPORT ATTACK	0	NOT ACCOMPLISHED - NO TWO-SHIP CAPABILITY DEMONSTRATED				
LOCATE TARGET	50	2.9	3	3	.92	Small AOI restrictive.
IDENTIFY TARGET	50	3.1	3	4	.90	Limiting clarity and lack of color.
ORIENT TO TARGET	21	3.0	3	4	1.07	Small AOI restrictive.
RESTRICTED PATTERN	15	3.1	3	3	.60	Unnatural TMB restrictions.
RANDOM PATTERN	18	2.9	3	2	.90	Gaming area restrictive.
TERRAIN MASKING PATTERN	6	2.2	2	2	.75	Minimum altitude on probe.
POP UP PATTERN	10	2.5	2.5	3	1.18	Small AOI-Orientation difficult.
CURVILINEAR APPROACH	11	2.8	3	3	.87	
MOVING TARGET ATTACK	2	1.0	1	1	NOT ADEQUATELY DEMONSTRATED.	
ORDNANCE ADJUSTMENT	0	NOT ACCOMPLISHED NO TWO-SHIP CAPABILITY DEMONSTRATED - NO VISIBLE WEAPON IMPACT				
REATTACK	22	3.0	3	3,4	.98	Small AOI

TABLE III-6 (CONTINUED)

other weaponry events could be performed in this device, but in an altered manner, as evident from the low ratings.

Tactical patterns, such as pop-up and curvilinear could be performed using this technology. Ratings were low in this area due to task performance alteration from real-world activity due to the small AOI.

Night tasking received low ratings. However, an optimum night lighting capability was discovered at the end of the evaluation that would substantially improve this area.

Formation tasks were not attempted due to fiscal and time constraints. Limited aerobatics could be performed as long as the pitch limit on the probe was not exceeded.

(b) Spatial Orientation Cue Analysis

Ratings for the spatial orientation cues are shown in Table III-7. All ratings are near the three (good) level, which is considered adequate to allow performance of the task, but not necessarily unaltered performance.

The attitude cue was often hard to determine in instances when the nose of the aircraft was far below the horizon and the AOI was in transit. Attaining correct distance and location cues was often complicated by the triangulation necessitated by the small AOI.

(c) Specific Reference Characteristic Ratings

The characteristics of selected items, objects, and features located within the visual scene were rated and appear in Table III-8.

Ratings on all features are near the very good level. This is due to the excellent TMB observed during the evaluation of this device. Low ratings in this area were usually a result of the monochrome display, which would occasionally make item differentiation difficult.

CUE	SAMPLE QUANTITY	MEAN RATING
ATTITUDE	475	2.903
DIRECTION	416	3.040
SPEED	472	3.119
ALTITUDE	475	3.063
DISTANCE	411	2.968
LOCATION	477	2.918
LINEUPS	476	3.118

TABLE III-7 - SPATIAL ORIENTATION CUE RATINGS (TMB/DOME PROJECTION)

CHARACTERISTIC	SAMPLE QUANTITY	MEAN RATING
SIZE	145	3.607
SHAPE	146	3.651
DETAIL	151	3.497
CLARITY	151	3.430
MOVEMENT	129	3.798
POSITION	136	3.706
ENVIRONMENT	149	3.657

TABLE III-8 - SPECIFIC REFERENCE CHARACTERISTIC RATINGS (TMB/DOME PROJECTION)

TOPIC	SAMPLE QUANTITY	MEAN RATING
FOV	475	2.794
IMAGE ALIGNMENT	60	3.02
IMAGE RESOLUTION	60	3.68
GAMING AREA	102	3.157
VISUAL SCENE ADEQUACY	174	3.091
REAL-WORLD COMPLEXITY	24	3.033
METEOROLOGICAL CONDITIONS	12	2.900

TABLE III-9 - ASSOCIATED RATINGS (TMB/DOME PROJECTION)

(d) Associated Ratings

Associated topics were rated and appear in Table III-9. Ratings were mixed from below good to very good. Many comments were collected in these areas and are addressed in the Limitations, Anomalies, and Improvements section and Significant Strengths section below.

The FOV was rated low partly because of the small AOI and accompanying head-slaved control. Imagery alignment refers to the point light source horizon alignment with the AOI horizon, which was slightly mismatched.

The 1500-1 scaled TMB's gaming area was too small for many tactical uses and the 5000-1 scaled TMB's gaming area was also restrictive with regard to some tasks. Visibility and weather restrictions were simulated, but presented some limitation as outlined in the section below.

(2) Limitations, Anomalies, and Improvements

(a) Image Generation

1. Edge Blanking Technique

The model boards maneuvering area was bordered by a buffer zone that was designed to restrict probe movement and prevent probe contact with the mirrored edges of the model board. When the aircraft crossed the boundary between the maneuvering area and the buffer zone, the model board imagery within the AOI was replaced with a simulated visibility restriction (i.e., cloud). Since the pilot would not visually determine the location of the buffer zone boundary, inadvertent flight too close to the model board edges resulted in unexpected and abrupt weather entry. Since actual inflight cloud entry is either gradual or at least predictable, this sudden blanking of AOI imagery was considered unrealistic and very distracting.

a. Proposed Technical Improvement

The rigid model visual system is comprised of two model boards, one 1500:1 and one 5000:1 scale. Each board is surrounded by a mirror to extend the observed terrain image to infinity. The probe and gantry are both limited by the computer software so that the probe will not contact the mirrors. When this limit is reached, the sky-plate on the probe is lowered and a pseudo-cloud cover is presented to the pilot until such time as the pilot has maneuvered his aircraft so as to fly away from the mirrors. Because the actual boundary between the mirror and the board is imperceivable by the pilot, it is not unusual for the pilot to fly into these mirrors and lose all visual reference. As stated, loss of visibility is abrupt and unexpected and was considered quite unrealistic and very restrictive.

A more realistic solution to this problem could easily be implemented by modification of the probe/gantry drive equations. A secondary boundary or warning path could be defined such that when the gantry/probe entered this area the sky plate would be driven in and out of the visual field in a random fashion, raising and lowering the visibility. Such a feature would permit the pilot enough advance warning to perform an evasive maneuver (180° heading change) before complete loss of all visual cues. A second and similar warning path could utilize a random drive of the focus servo in place of the random drive of the sky-plate and would provide a similar warning situation to the pilot. Risk associated with the above solution is low.

b. Estimate of Proposed Improvement

The proposed sky-plate warning would provide adequate warning to the pilot to avert total weather conditions. Realizing that cloud simulation in the context of the real world is difficult, this proposal would provide adequate pilot warning. The negative aspect of flying into and out of invisible clouds would be distracting; however, mission accomplishment should not be affected with judicous mission planning. The use of the focus coil may cause severe eye strain due to focus problems, however, this assumption cannot be proven until actually tested.

2. Gaming Area

The 1500:1 scale TMB gaming area (approximately 3 X 11 NM) was generally too small for tactical operations. The limited size of the board, represented by the 3 NM dimension caused numerous undesirable encounters with the cloud effect used for edge blanking.

There were many items, objects and features near the edges of both model boards that were difficult or impossible to use for weaponry targets. Those within the buffer zone were not available for attack due to the lateral and horizontal displacement limits of the probe. Those on the boundary between the TMB's maneuvering area and buffer zone had to be attacked on a heading that would avoid the edge blanking system. Although restricted attack headings are often necessary, weaponry patterns should be planned and flown in accordance with tactical considerations and not as a result of inherent model board limitations. This constraint might reduce the effective size of the model board's gaming area due to the necessary positioning of tactical targets.

a. Proposed Technical Improvement

The gaming area on the 1500:1 scale board is generally too small for tactical operation. An aircraft flying 350 knots (590 ft/sec) can fly the length of the board (11 NM) in 2.0 minutes and the width (3 NM) in 38 seconds. On the 5000:1 board, with the same aircraft speed, the pilot can fly for over 6.5 minutes over the length of the board (36 NM) and over 2.0 minutes widthwise (13 NM). The 1500:1 board was designed to provide highly detailed modeling in the area of the runway and approach terrain. To properly utilize the model board system used in this evaluation, one should take off on the 1500:1 board, switch to the 5000:1 board for tactical maneuvers and return to the 1500:1 board for landing. The 1500:1 board was not designed to accommodate tactical missions of high performance aircraft. A board appropriate for such missions could easily be developed. The technical risk is low.

The 1500:1 board was not designed for high performance aircraft in a tactical flight regime. If a terrain model board was to be designed specifically for air-to-ground weapon delivery for high performance aircraft, the targets would be placed in a position such that they could be engaged from any heading without restricting weaponry patterns. Risk is low.

b. Estimate of Proposed Improvement

The proposed solution is adequate, providing the small scale model board (i.e., 5000:1) is large enough to permit ingress and egress from the target area and modeling SOA will permit development of small tactical targets (i.e., tanks).

3. Ceiling and Visibility

There appeared to be a perpetual ceiling located slightly above the aircraft at all altitudes. The distance between the aircraft and this perpetual ceiling did not appear to vary as a result of changing the aircraft's altitude. Instead, this ceiling appeared to be fixed to and move with the aircraft. (This constant ceiling was evidently a by-product of the technique used to prevent the observation of associated video support equipment during instances when the probe would have been allowed to scan above the sides of the model board assembly.) Due to the presence of this persistent ceiling, it was impossible to judge the distance below an actual overcast condition. Penetration of an overcast in actual flight is normally predictable and therefore expected by a pilot. However, weather entry was unpredictable in the simulator because of the perpetual ceiling blocked the overcast from view.

The perpetual ceiling also limited the pilot's ability to observe terrain or cultural features which protruded above the aircraft's altitude during inflight maneuvering. It is anticipated that this constraint would limit takeoff, landing, visual navigation and low angle weaponry tasks in areas with significant vertical relief.

Simulated inflight visibility appeared to be a distant weather restriction as opposed to a gradual degradation of terrain or cultural detail. This resulted in the unrestricted use of model board features located between the aircraft and distant fog bank. The lack of a gradual visibility restriction was not representative of actual inflight weather.

a. Proposed Technical Improvement

The perpetual ceiling located above the aircraft is a characteristic of all model boards and is used to keep the probe from viewing a reflected image of the gantry in the edge mirrors. This ceiling does remain relatively constant in front of and above the aircraft and does move with the aircraft over a large percentage of the board.

The visual probe is equipped with a sky-plate which is a prism of glass that is clear on the lower tip and gets progressively more translucent towards the upper end. This sky-plate is lowered so that a hazy-horizon is obtained and also completely lowers when the pitch limit is exceeded or when the edge boundary is entered. This sky-plate can obscure vision. When the total vertical field of view is only 36° (± 18° from horizon) imagery above the 18° upward cutoff is outside the field of view. This can cause problems at low altitude. Because of the geometry of the problem, when flying at low altitudes it is possible that the top of a mountain may not be visible. Risk is low to medium.

b. Estimate of Proposed Improvement

Apparently this particular problem will remain with model board generation techniques. Limitations as outlined will restrict operational employment.

4. Night Lighting

Unidirectional runway lights restricted the performance of night approach, landing, and weaponry tasks when performed in conjunction with the runway complex. Since the lights could only be seen within a narrow band of the final approach course, the pilots were not always able to determine their position in relation to the airfield complex.

During night approaches and weaponry tasks, the scene appeared to darken as the aircraft descended below approximately 500' AGL. This darkening effect resulted in the unnatural appearance of a shadow (possibly cast by the gantry assembly) which was constantly in the pilots view during night operations at low altitudes.

a. Proposed Technical Improvement

The night lighting scheme on the model boards is both omnidirectional and unidirectional. The strobe lights, for example, are unidirectional as in the real world. In an attempt to increase the light level of the omnidirectional lights, a pair of unidirectional lights were used as shown below:

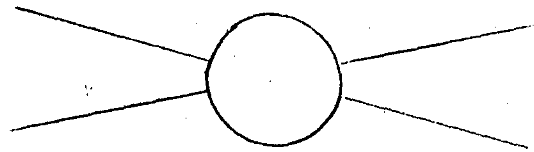


FIGURE III-1 - RUNWAY LIGHTING DIAGRAM

Because of this situation, there are areas to the left and right of the runway area that are outside the visibility sector for these lights. To use totally omnidirectional lights may degrade the light intensity which was felt to be a more serious problem. Risk is low.

Shadows were noticed below 500' AGL which can possibly be attributed to the gantry system for the probe. Small, high intensity quartz lights surround the probe and are normally lit during day approach. At low levels when the probe gets close to the board, these lights are designed to prevent these shadows. This problem may be due to a misalignment of these cosmetic lights. Correction is low risk.

b. Estimate of Proposed Improvement

Lack of omnidirectional lights around airfield complex severely restricts training utility for night flights. A possible solution to the shadow observed from 500 feet may lie in the use of a reduced cosmetic light level. This would provide just sufficient light to eliminate the shadow effect.

5. Probe Pitch Limit

When operating with head-slaved AOI control, the probes viewing direction was commanded by a combination of the pilot's head position and the aircraft's attitude. Whenever this probe angle exceeded approximately 45 degrees, a visual scene blanking condition (simulated cloud entry) was encountered. The most obvious result of this constraint was the inability to properly perform high angle weaponry tasks. A constraint which was not as obvious, but of equal significance, was the pilot's inability to look where required in order to correctly perform various tasks. For example, the pilot could not approach a vertical view of VFR navigation checkpoints, overhead traffic pattern checkpoints, weapon delivery impacts (assuming availability), or employ normal methods of aircraft position identification. Accordingly, pilot performance of many tasks was limited, altered, or impossible due to this restriction.

During operations using target fixed AOI control, the probes viewing direction depended on the target's location and the aircraft's horizontal and vertical distance from the target. As the aircraft approached a selected target in level flight, the probe's pitch angle increased in order to keep the AOI centered on that target. As the probe's angle reached approximately -45 degrees, a simulated cloud entry was encountered. Thus, it was impossible to fly directly over a target or perform high angle weaponry tasks at the proper horizontal range from the target. As in head slaving operations, this restriction limited, altered, or prevented the performance of many tasks.

a. Proposed Technical Improvement

The pitch limit on the probe is +24° and -47°. When either of these two limits is reached, a simulated cloud entry is experienced by the pilot until the probe commands come back within the operational limits of the probe. This restriction is a restriction of the particular model board system used in the evaluation. A 90° pitch down axis can be obtained at low or no risk. Such an addition to the rigid model visual system would permit the pilot to fly over targets, perform high angle dive bombing missions and would eliminate many of the unnatural and distracting visual scene blankings. In the target-slaved mode the same pitch limit restrictions are found as above. These problems would also be eliminated with the unlimited probe modifications mentioned above.

b. Estimate of Proposed Improvement

It appears that this limitation can be completely remedied.

(b) Image Display

1. AOI Size

Model board imagery was displayed within a 48 degree (horizontal) by 36 degrees (vertical) area of interest surrounded by an earth/sky background. Since the earth/sky projection was relatively featureless, all aircraft direction, distance, location and lineup cues, as well as the targets position, had to be obtained from imagery within the AOI. Since the amount of viewing area was restricted by the size of the AOI, it was often necessary to move the AOI in order to view the target and obtain the necessary aircraft orientation cues. AOI movement was a continuous process since a determination of aircraft and target location had to be constantly updated, using a triangulation technique, in order to maneuver within the environment and perform various tasks. This continual triangulation process was achieved by performing an unnatural number of head movements instead of a more normal combination of head and eye movements. The amount of head and AOI movement was further increased due to a lack of imagery in the peripheral areas. Since the position of an object (i.e., the runway) could not be monitored using peripheral vision, the pilot was required to place the AOI in the objects direction throughout task performance (i.e., landing). A simple glance with a combination head and eye movement would not suffice because the AOI had to first be positioned with a preliminary head movement. When the AOI was placed near the horizontal or vertical limits of the field of view, the resulting head and shoulder movements were unnatural, uncomfortable, and very distracting. (A shoulder movement was often required so that the head could be sufficiently positioned for correct AOI placement.) Task performance was significantly altered due to the limited size of the AOI.

a. Proposed Technical Improvement

The 60° diagonal field of view (36° in height and 48° in width) is a typical field of view for television probes associated with model board systems. Some prototype wide angle probes are now being demonstrated, some as wide as 100° in width and 50° in height. This only solves one problem and that is in the image detection phase and does not permit an entire solution to the problem in that it does not address the image display problem. In a projection system type of display, the ability to project a planar image on a spherical surface becomes increasingly more difficult as the width of the image increases. It is possible that a series of 60° diagonal probes and projectors could be used to display a wide angle picture but restrictions on size and weight would presently create problems by degradation of motion performance. Risk in this area is medium.

b. Estimate of Proposed Improvement

Limitations due to the narrow AOI are a significant problem. The suggested improvement provides a wider FOV; however, it also implies that resolution at maximum AOI excursions may be a problem. A complete solution to this TMB/Dome Projection anomaly may well be unattainable. A wider FOV is required, however, sacrificing resolution and clarity is diametrically opposed to the desired results. Significant reduction of training utility would be experienced in the performance of most tasks.

The basic premise that a wider AOI would improve these limitations is highly conjective. Evaluation results indicate the essential need for a wider AOI, however, the data did not predict a minimum requirement. Quantification of operational improvement based upon a theoretical assumption in this significant area is extremely difficult, if not hazardous. The actual requirements for AOI size can only be gained from further evaluations of increasingly larger AOIs.

c. Additional Information

Presentation of AOI fields of view up to approximately 70° diagonal can be accomplished within existing technology. Expansion of the field of view to 120° presents numerous image projector problems related to image brightness, image resolution, and image geometry. Existing technology will not support use of a single image projector to expand the AOI beyond 70° without severe compromise in all of the above areas. A dual projector approach is feasible (each projector handling half of the total AOI). Such a system has not been developed. Moreover, such a dual projector would impose a special problem related to image generation. Development of the wide field-of-view display projector is medium risk and would take approximately two years.

2. Head Slaved AOI Control

Head slaved control of AOI placement was briefly interrupted on many occasions throughout the evaluation. These occurrences seemed to be associated with rapid or exaggerated head movements. Two such tasks requiring considerable head movements were weaponry roll-in and dive-angle establishment. To properly accomplish these tasks, the pilot had to continuously move his head in order to cross-check target position, aircraft location, and cockpit indications. On occasion, this rapid cross-check sequence resulted in the loss of head-slaved control. The pilots felt that it was unnatural, untimely, and distracting to delay task performance until control was regained.

During the final portion of landing and weaponry tasks, several pilots experienced difficulty lowering the AOI in order to keep the necessary imagery (i.e., target, runway, touchdown point, etc.) within the viewing area. These pilots were required to use an unnatural head position (i.e., chin-in-chest technique) in order to complete the landing or weaponry task.

It was distracting to look into the cockpit and have the AOI illuminate the instrument panel.

a. Proposed Technical Improvement

The periodic interruption of head slaved AOI control was due to improper placement of the infrared helmet sight sensors. Ideally, the sensor units should be placed approximately 12-24 inches from the helmet. In this simulator, due to the superstructure used to support the target-projector platform, the sensors had to be mounted less than 12 inches from the helmet. As a result, the range of coverage was severely limited. Rapid head movements in the extreme positions for head azimuth and elevation can go outside the sensor surveying area and cause loss of AOI control. If a head-slaved AOI was a requirement, then the simulator cockpit could be designed to accommodate the sensors for assured continuous head movement. Risk is low.

All unrealistic head movements were not a result of the head-slaving aspect of this system. Some were a direct result of the limited AOI. Had a larger presentation been available, such head movements would have been reduced inversely with AOI size.

The problem of the AOI shining into the cockpit when the pilot was viewing his instruments is a problem which can be eliminated by mapping the cockpit area to determine the point at which the displayed imagery enters the cockpit and limit switches can be set in the software dive program to prevent this problem. Risk is low to medium, depending on the sophistication of the situation.

b. Estimate of Proposed Improvement

Use of a helmet-mounted sight specifically designed and integrated into an AOI system should minimize the interruption problem. Additionally, improvements in helmet-mounted sights which include eye excursion detection and drive outputs may further reduce this problem.

3. Target Slaved AOI Control

When operating using target slaved AOI control, the pilots could not properly determine their location or altitude due to the restricted viewing area.

a. Proposed Technical Improvement

Once again, an unlimited pitch axis on the probe and a wide AOI would help alleviate this problem. Risk is low.

b. Estimate of Proposed Improvement

Limitations would be less objectionable with proposed incorporation of unlimited pitch axis and wide AOI.

4. AOI Frame

The rectangular shape of the AOI occasionally induced an artificial bank or pitch sensation. Several of the pilots considered this occurrence disorienting because of the attitude corrections which they introduced in response to the false visual cues.

a. Proposed Technical Improvement

The rectangular presentation which caused some pilot disorientation is again a function of the field of view of the probe. With a 60° diagonal FOV, the edges of the rectangle are distinct whereas if the imagery displayed had been larger, the edges would be far enough removed from the foveal view that the distinct rectangular shape would be less objectionale.

b. Estimate of Proposed Improvement

This limitation would be reduced with a larger AOI.

5. AOI Fading

Imagery within the top portion of the AOI became indistinct when performing tasks on the 5000:1 scale TMB at altitudes below approximately 3500 feet. Image fading was more pronounced when the pilot's line of sight was parallel to the earth's surface and the probe was in close proximity to and pointed towards an edge mirror. This phenomenon affected the clarity of imagery in the upper portion of the AOI and resulted in the lack of a distinct horizon. Pilots were distracted when attempting to obtain spatial orientation cues (altitude, location, lineup, etc.) from the upper portion of the AOI.

a. Proposed Technical Improvement

The AOI was found to be indistinct near the upper portion of the terrain image, particularly when flying parallel to the earth's surface (zero pitch angle) and near the mirrors. The reason for this is that when the probe is near the mirror, the terrain images become a reflected image which is not as bright and has some distortions (see Figure III-2).

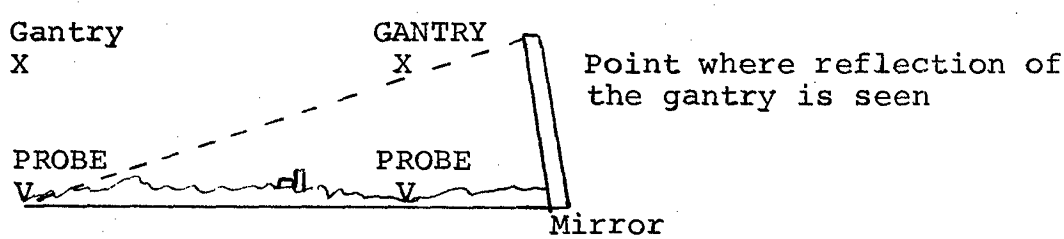


FIGURE III-2 - TMB IMAGE REFLECTION

As a result, the terrain near the top of the scene begins to be clouded by the sky-plate. Further work on compatible software for the visual probe, sky/earth projector and sky-plate will help alleviate this problem. Risk is low.

b. Estimate of Proposed Improvement

This limitation can be significantly reduced.

6. Restrained Head Movement

Pilots had to unnaturally position their heads in order to place the AOI where necessary during task performance. For example, several pilots had to tilt their heads forward (i.e., chin-in-chest technique) in order to lower the AOI during landings and weaponry deliveries. Pilots also had to tilt their heads to the side to compensate for the probe pitch limit. All pilots had to rotate their body and head in order to slew the AOI during task performance requiring over-the-shoulder observations of terrain or cultural features.

Pilots are accustomed to moving their heads freely during actual aircraft flight. This freedom to place the head as desired was denied in the simulator during head-slaved AOI operations due to the interdependence of AOI positioning and head placement. Free head movement, possibly taken for granted in an aircraft, was especially appreciated when available in the simulator (i.e., during target-slaved AOI operation).

a. Proposed Technical Improvement

The requirement for the pilot to assume unnatural head movements is the result of several compounding factors. The first is that the typical helmet for a helmet sight system has a poured liner and is fitted to the particular pilot. The helmets used were the only ones available for this evaluation. They were older helmets with removable pads. As a result, the reticle used to boresight the helmet was not always exactly over the eye where it should have been.

The tilting of the head to the side to compensate for pitch probe problems would obviously be eliminated if an unlimited pitch axis was placed on the visual probe.

A second and more difficult problem to solve is that of slewing the AOI to the far azimuth limits of the sphere. The reason for this is that the AOI was head slaved (i.e., it was fixed to a vector aligned with the head). As a result, to slew the AOI back to the back corner of the sphere would require a head movement of 109°. Such extreme head movements are anatomically impossible. In a real aircraft situation, the pilot would probably move his head a maximum of 60° to 70° and use his eyes to see back to the extreme positions. There are two possible ways to alleviate this problem. One would be to drive the AOI display not only with head position, but also with eye position. Such a device is commercially available and could be custom built into the helmet. A second method would be to make the display nonlinear. The drive could be a one-to-one from 0 $\pm$ 50°, two-to-one from 50° to 60°, and three-to-one from 60° to 75° of head movement. Hence, when the head reached the 75° position, the display would be in the back corner of the sphere.

There are problems which could be anticipated with the nonlinear system described above When the display is commanded to move by a one-to-one movement of the head, the pilot knows exactly where to position his head to obtain the proper visual segment. With the nonlinear system, the AOI positioning would not be as straight forward and a wide AOI would considerably help such a system in that the edge of the AOI would be in the back corner of the sphere using a one-to-one drive when the head was 73° with respect to the center boresight position. AOI placement by definition follows the head in the head-slaving mode. An unlimited pitch limit on the probe and wide angle AOI would allow head movements to be more realistic. Also, with the large AOI, the target slaved would be considerably more useful. Risk assessment is medium.

b. Estimate of Proposed Improvement

Incorporation of a wider AOI and unlimited pitch axis would provide a much more usable system. The inability to freely move the head, while improved, does not appear totally solved. The solution apparently lies in incorporation of a more responsive detection and camera servo system. Employment of high gain servo systems may lead to dampening problems in the AOI display. This area must be considered a tradeoff between head movement and camera drives, with no complete solution.

7. Field of View

Several pilots indicated that the horizontal FOV might have been insufficient when performing tasks which required maximum lateral viewing. For example, when flying overhead landings or random attacks, pilots were often required to view touchdown points or tactical targets located as far aft as 135 to 150 degrees from the aircraft's centerline. However, due to the difficulty encountered during AOI placement, pilots were unable to accurately determine if the FOV horizontal boundary was actually the limiting factor. Likewise, due to a probe pitch limit of approximately 45 degrees, the pilots were unable to determine if the vertical viewing area was sufficient for complete task performance.

a. Proposed Technical Improvement

A much larger FOV (two or more projectors) could be developed and be accommodated by enlarging the size of the sphere. The larger sphere would thus allow better placement of the projectors (assuming the same relative location of the projectors were maintained) and consequently increase the horizontal FOV. A second alternative would be to reposition the projectors (i.e., below the cockpit platform). In the case of the vertical FOV, the target projector has no elevation restrictions, thus a full 90° pitch axis probe would increase the usable vertical FOV provided by increasing the size of the dome or relocating the projectors. Risk is low.

b. Estimate of Proposed Improvement

The proposed solution would appear to eliminate the problem.

8. Earth/Sky Projector

Although the background scene, as presented by the earth/sky projection system, supplied important aircraft attitude cues, its featureless characteristics added little to the determination of aircraft direction, distance, location, and lineup cues. Combined with the limited size of the AOI, the lack of background detail made the adaptation to this visual system increasingly difficult. Several pilots felt as if they were viewing the AOI imagery through a tunnel, which occasionally made it difficult to determine the aircraft's altitude and relative distance from a target. This sensation was more prevalent when the aircraft's combined altitude and attitude was such that the earth/sky horizon was vertically displaced to the edge of the pilot's peripheral viewing area (i.e., steep dive angle). This tunnel vision sensation may have been partially caused by the featureless and darkened earth/sky background.

a. Proposed Technical Improvement

The sky-earth horizon display is a passive display and does not provide as much detail as might be required to obtain all the necessary attitude cues for proper control. Such lack of peripheral detail would be eliminated using a wider angle probe.

The smaller the AOI, the smaller a percentage of sphere area is covered by the display and the more tunnel-like the display appears. A wide angle projection system would help eliminate this situation. Risk is low.

b. Estimate of Proposed Improvement

A wide field of view would help decrease the effect of this limitation.

9. AOI Frame Distortion

The AOI frame occasionally lost its rectangular shape as it traversed the inside of the dome. Although noticeable, this apparent distortion did not alter task performance.

a. Proposed Technical Improvement

A projection system is made to display an image on a flat surface. Where the image is displayed on a curved surface some distortion will occur. The larger the AOI, the more distortion. Raster correction and keystone correction have been employed to help alleviate this problem. Risk is low.

b. Estimate of Proposed Improvement

Raster correction and use of a larger dome would reduce the effects of this problem.

10. Earth/Sky and AOI Horizon Mismatch

The pilots were frequently required to place the AOI on or near the horizon in order to perform certain tasks. At this position, a horizon was also displayed within the AOI and discontinuity between the two horizons became apparent. For example, the AOI horizon was displaced above the background horizon when flying the final approach for landing in such a way that the mountainous features of the earth/sky background were superimposed over the runway image. This same horizon overlay was also observed during low angle weaponry deliveries adding to the difficulty of determining the correct target. The horizon mismatch complicated task performance and was very distracting.

a. Proposed Technical Improvement

The reason for the known mismatch can be traced back to the drive equations. The sky/earth projector was being run on a different feedback path than the probe/target projector. A second problem is that the sky plate is programmed, based on altitude, distance from the mirrors, pitch angle, etc. As a result, since the sky/earth is not subject to these limits, a noticeable difference can result. Thirdly, the equations used to drive the sky/earth projector were based on spherical earth assumptions whereas those for the terrain board were flat earth equations. At low altitude the two should line up quite well, however, at high altitude, a noticeable difference will occur. The problem can be alleviated through additional software work on both the sky/earth display, the target projector, and the probe. Risk associated with the above correction is medium.

b. Estimate of Proposed Improvement

Incorporation of the proposed solution would minimize any mismatch.

11. Imagery Movement

Normally, AOI imagery would move smoothly within the FOV in response to changes in the aircraft's attitude and location. However, with small abrupt head movements, these same images would exhibit additional motion that could not be attributed to changes in the aircraft's position. The inappropriate movement (i.e., jitter) complicated the pilot's attempts to line up with a runway or target when performing low altitude tasks. During night operations, this undesirable movement caused the runway lighting to blur, thus complicating pilot performance of night landing and weaponry events.

a. Proposed Technical Improvement

Imagery jitter can be attributed to abnormally rapid head movements associated with having to continually move the head to cross check target position, aircraft location, and cockpit instrumentation. A wide angle AOI would reduce the need for continual head movement and hence would help to eliminate imager jitter. Additionally, software refinements in target projector and probe drive programs will improve performance.

b. Estimate of Proposed Improvement

A wide AOI will reduce, but not eliminate, this problem. Cross checks by their very nature require rapid head movement. During critical phases of flight (i.e., landing, weapons delivery, etc.), a constant cross check is taking place so adjustments in airspeed, pitch, and altitude can be made. Denying or restricting these normal checks placed a severe and unnatural restriction on the pilots. The negative training aspects of this feature are of considerable concern.

12. Image Identification

The two model boards associated with this visual simulator system were constructed with a high degree of detail and accuracy. However, when viewing the video display in the dome, the pilots were unable to identify numerous cultural items or terrain features. In some cases, the pilots could not determine an objects size, shape, or detail from the video image. For example, it was very difficult to locate and attack a bulldozer situated in a gravel pit on the 1500:1 scale model board. The bulldozer was of sufficient size to have been easily identified in actual flight, but could not be recognized at normal distances in the simulator. Likewise, during attacks on the SAM site (located on the 5000:1 scale board) the pilots experienced difficulty identifying the particular structures associated with a SAM installation. Although items similar to the bulldozer and SAM site used in these examples should be difficult to identify at long slant ranges, their distinguishing characteristics should have been discernable at the closer ranges associated with weapons deliveries flown in this evaluation (i.e., within approximately one mile). In contrast, shorter slant ranges (approximately 1000 feet) were required in order to detect the proper level of detail necessary for image identification. In other cases, where the size and shape of an object could be determined, the pilots still encountered difficulty identifying particular items due to the homogeneous shading. For example, a gravel pit was often mistaken for a lake due to a physical similarity (same size and shape) and display similarity (same shade). Individual objects that were colored differently on the model board would be shaded identically when displayed in the visual scene. When such objects were adjacent on the model board, they would blend together due to similar shading. This lack of distinct shading made the determination of target size, shape, and detail difficult. In summary, the pilots were unable to locate and identify numerous items, objects, or features in the visual scene due to a combination of homogeneous shading and unidentifiable detail.

a. Proposed Technical Improvement

Several things impact the pilot's ability to identify images on the model board. The inability of the pilots to distinguish between the gravel pit and the lake can be attributed to lack of color in the evaluated display system. The reasons there is no color displayed in the AOI is because it would take a color projector which is considerably larger and heavier and such additional weight would degrade motion performance. Secondly, a light valve cannot be used because of the sensitivity that it has to motion. Risk is high if the same motion system is used. Risk is low if other motion systems or no motion is used.

The inability of the pilot to see an object at the same slant range as in actual aircraft is a deficiency of any television type visual system whether it be CIG or model board. A formula for determining the target size/slant range for identification is given below:

N = number of effective resolved lines across the sensor's FOV.

For the system evaluated, the following values are assigned to N:

$N = 420$ vertical $= N_V$

$N = 550$ horizontal $= N_H$

M = number of resolved lines across a target for detection or identification

detection $m = 4 = M_D$

identification $m = 8 = M_{ID}$

L = maximum dimension of target (feet)

S = slant range (feet)

The maximum permissible field of view for the sensor is then:

$$\theta = (2N/M) \tan^{-1} \text{ or } \arctan (L/2S)$$

Since we have a 60° diagonal field of view, θ is fixed at 60°.

Thus, if one specifies L, M, and N one can calculate S. For example, given an M60A2 tank 23 feet wide, engaged from the side then:

$N_H = 550$

$M = 4, 8$

$L = 23$

S = unknown

$\theta = 60°$ diagonal (48° horizontal, 36° vertical)

Rearranging the terms and solving for S yields:

$$s = \frac{L}{2 \tan \frac{M\theta}{2N_H}}$$

for detection (M = 4)

$$s = \frac{23}{2 \tan \frac{4 \times 48}{2 \times 550}}$$

$$= \frac{23}{2 \tan (0.174545)}$$

$$= 3774.9 \text{ ft} \sim .715 \text{ miles}$$

for identification (M = 8)

$$S = 1887.4 \text{ ft} \sim .357 \text{ miles}$$

Obviously, in unlimited visibility in the real world, one can see considerably further than the above calculations show. In CIG systems, the target image can be made larger at greater distances so the pilot can see it at a typical slant range and then can be gradually reduced to the proper size as the pilot approaches the target. Risk is high.

b. Estimate of Proposed Improvement

As stated the formula provides a possible answer by increasing the horizontal and vertical resolution. For instance, the camera employed in this system is capable of operation at a higher scan rate which would improve vertical resolution with a corresponding degradation in horizontal resolution with the same bandwidth. Realizing the generation system operates at 625 lines, this system would require significant performance improvements.

(c) Other Simulator Features

1. Motion

Simulator heave displacement appeared insufficient compared to the amount of aircraft pitch input. This may have been the cause of the vertical oscillations that the pilots experienced throughout the evaluation.

The motion system appeared to create a negative G sensation immediately following the release of a larger G application. The G meter continued to display a positive indication (between one and two G's) during these occurrences.

a. Proposed Technical Improvement

Simulator heave displacement could have been insufficient compared to the amount of aircraft pitch input if the center of gravity of the aircraft was improperly modeled.

The sensation of negative G immediately following the release of large G applications indicates that the washout circuitry might not be correct or should at least be tuned for the particular aircraft being simulated.

b. Estimate of Proposed Improvement

Improvements in software drive and washout equations should improve these limitations.

2. G-Suit

The G-suit configuration provided with the device was not identical with the evaluation pilot's G-suits. Since the inflation rate was designed for the G-suit used in conjunction with the device, the G-force simulation was inaccurate. Software controlling the G-force simulation would require program changes. There is no risk.

a. Proposed Technical Improvement

Further studies are required in the future in this area.

b. Estimate of Proposed Improvement

Concur.

3. Cockpit

Several pilots noted that the temperature in the cockpit area reached an uncomfortably high level by the end of a one-hour mission.

The noise of the display projectors movement was somewhat distracting.

It was felt that pilot egress from the cockpit would be safer and quicker during an emergency if a quick disconnect for the helmet-mounted sight connection and a safety rope for dome egress were provided.

a. Proposed Technical Improvement

Cockpit temperature was felt to be excessive by several pilots. The sphere does have a ventilation fan but the pilots were wearing flight suits, g-suits, and helmets (i.e., normal flight gear), and ventilation is presently not sufficient.

The audible noise associated with the target projector can be attributed, in a large part, to the rapid head movements presently required in the head-slaved mode due to the small AOI. A large AOI would enable unrestricted eye movement, less necessity for head movement, and hence, less target projector movement which would cut down on the audible noise.

A safety rope for dome egress could be provided at no risk if the using organization determined the technique to be the most appropriate solution. With the configuration of the device used for this evaluation, it is felt that the console operator is in a more advantageous position to determine the safety of the pilot regarding dome egress. Safety procedures were thus written accordingly. The helmet sight system includes a quick release plus, but it needs to be located in a more readibly accessible position.

b. Estimate of Proposed Improvement

The technical improvements would appear to remedy the limitations on the device evaluated. Operational considerations and requirements of a using command may require different safety procedures.

4. Auditory Cues

An audio cue to indicate when the speed brake was extended would have been beneficial. This cue would provide the pilot feedback information regarding the position of the speed brake.

a. Proposed Technical Improvement

Addition of this feature is a low risk item.

b. Estimate of Proposed Improvement

Concur.

5. Aircraft Dynamics

Pilots indicated that the aircraft was unusually sensitive about the roll axis. This may have been the cause of several lateral oscillations that the pilots experienced throughout the evaluation.

a. Proposed Technical Improvement

A possible error in the probe pitch axis is suspected simply due to the inertia of the servo system. Statically, small angular errors have been found to exist in the system due to the lack of a feedback system for the pitch axis servo. This error is quite small, on the order on one-half a degree or less and does not effect such tasks as power approach and landing, which was the primary reason for which the system was purchased. Such errors in a high accuracy task such as weapons delivery can result in significant errors. An example can be made of a static delivery at -15° pitch angle with a 0.6° error. Such an error at this orientation can result in an on-the-ground error of 100 feet. When integrated into a full simulation where the dynamics of the target projector, simulator motion system, probe motion and computer noise can also be a factor, further degradation of this situation may occur. An attempt should be made in the future to look at this problem. Risk is low.

b. Estimate of Proposed Improvement

Concur. The addition of improved roll axis servos, which incorporates improved feedback, does not present any technological problem.

6. Weapon Scoring

The accuracy of weapon scoring seemed to vary between delivery passes. This variance did not appear to be a logical consequence of changes in release parameters. Accordingly, pilots experienced moderate difficulty in correlating their predicted score with the computer score. Although purposely not attempted during this evaluation due to program constaints, precise strafe scoring (percentage of hits versus rounds fired) would be required to properly simulate air-to-ground gunnery.

a. Proposed Technical Improvement

The ability to accurately score weapon delivery is a very difficult task. There are a number of system anomalies which degrade weapon system accuracy. First, a number of the servo systems in both the visual display system (target projector) and the visual image generator (TMB) are open-loop position servos which have no feedback system for accurate position. Secondly, the resolution of the visual system may be a limiting factor in determining accurate target location. Another problem is that the pilot may not be adequately sensing the wind and turbulence to adequately compensate for proper weapon release but that these environmental conditions are properly affecting the ordnance. Additional studies will be required to determine the static and dynamic accuracy of the TMB/Dome system and to further refine the weapon delivery software.

b. Estimate of Proposed Improvement

Bomb scoring for simulation is a high priority requirement and accurate scoring is mandatory since it provides the only feedback to the pilot on corrections he made during the final stage of delivery. Manual bombing requires a series of corrections to achieve accuracy. Each pilot is aware of the perfect set of conditions needed to drop the perfect bomb; however, these parameters are seldom achieved due to winds, buffet and incorrect/overcorrect inputs by the pilot. To overcome these natural deterents, a series of corrections to airspeed, dive angle, G loading, and release altitude are required. Inaccurate bomb scoring fails to provide the pilot with feedback on how well he applied these corrections, an invaluable tool for any air-to-ground simulator. Large miss distances, in face of the pilot attempts to correct, would cause frustrations and soon would lose pilot interest since he continually fails to improve. Bomb scoring should be both accurate and in real time, both visually and in hard copy.

7. Computer Synchronization

Computer synchronization of the probe's location was interrupted on numerous occasions. Subsequent visual reset required time, interrupted task performance, and was distracting.

a. Proposed Technical Improvement

Loss of computer synchronization of the probes position was due to spurious voltages resulting from noise in electrical grounding. Such noises, when converted to drive signals for the probe, can command the probe beyond its normal limits. Software sensed these unsafe conditions and retract the probe to prevent serious damage. Proper grounding is low risk.

b. Estimate of Proposed Improvement

This solution would correct the problem.

(3) Significant Strengths

This section lists the significant strengths demonstrated by this technological approach to air-to-ground simulation:

(a) Scene Content

The content and detail in this TMB/Dome projector system afforded excellent speed and altitude discrimination when at relatively low altitude. These factors made task performance during low altitude deliveries and tactical operations more natural. The additional scene content made target selection more realistic because the target had to be selected from a cluttered environment rather than being obvious. For the same reason, takeoffs, and landings were more natural. The increase in usable cues, however, was offset by the small size of the AOI and by the limited supporting background cues.

(b) Clarity and Resolution

Good clarity and resolution allowed more natural use of the detailed scene content within the AOI. Objects could be used as cues for weapons delivery at more natural slant ranges.

(c) Head Slaved AOI

Discounting its small size, the head-slaved AOI allowed more flexibility than the target-slaved AOI in that the pilot was not restricted to looking only at the immediate target area.

(4) Required/Optimized System Performance Characteristics and Potential Capabilities (TMB/Dome)

This section combines the demonstrated capabilities, significant strengths, and proposed technical improvements into a required/optimized TMB image generator and dome display system. It is important to remember that this optimized system is a departure from the system evaluated and the data collected during Phase II. Optimized characteristics that are not considered SOA are identified by the need for research. It should also be noted that the optimized systems include only characteristics that are considered relevant and relatable to the Project.

(a) Required/Optimum TMB Image Generator System Performance

1. Camera Probe

Since the camera probe is the first step in the video generation chain, it must possess the stringent optical requirements to initiate the complex scene generation needed to accomplish air-to-ground weapons delivery. The probe must be capable of passing high resolution imagery over an extremely wide field of view to the camera system without distortion or degradation. The operating AOI needs considerable expansion beyond the demonstrated system (60° diagonal). Further research is needed to determine the minimum AOI. The probe should be capable of operating between a simulated 20,000 foot altitude down to the runway eye height of the aircraft being simulated. The dynamic qualities of the probe head must meet the acceleration and rates of the aircraft it simulates (i.e., roll rates, pitch, and yaw accelerations, etc.). The probe must have unlimited freedom in the roll and pitch axis. The horizon of the AOI and the horizon of the sky/earth display must be aligned to provide the matched horizon cues which are essential in establishing aircraft spatial orientation. The probe should be ruggedized to avoid serious damage should inadvertent contact with the model board occur. Probe excursion limits must be controlled by both mechanical and software fail safe protection systems. Miniaturization of the probe head is required to allow operation in close proximity to mountains and structures.

2. Camera

The camera needs to have the inherent qualities which will provide both static and dynamic high resolution image output signals in all operating envelopes (i.e., day, night, dusk, high and low altitude). This feature is required to insure adequate target discrimination and location task accomplishment. As tested in Phase I, the static resolution of both cameras in the camera/model systems was drastically reduced when dynamics were applied to the systems. Further research is required to improve the horizontal and vertical resolution characteristics of cameras now available. Research is also required to improve camera response to low light levels if effective dusk and night tasks are to be accomplished.

3. Moving Targets

Various designs for adding moving models to the model boards has been theorized. The only viable method appears to be through an insert principle using a separate image generator system (i.e., CIG). The CIG system would be integrated into the camera model video chain and would supply the weapons impact, tracer fire, air-to-ground and ground-to-air missile effects, and all moving targets in the airborne and ground environment. Further research is required to determine the number of edges required, best integration design and prove the feasibility and utility of this design approach.

4. Terrain Model Board

At least two TMBs are probably required to provide the large gaming area necessary for tactical operations and yet permit the very low eye heights required for takeoff and landing. For example, to provide a gaming area of 15 NM by 40 NM for tactical operations requires the usable portion, inside the buffer zone, to be 18 ft. by 48 ft. at 5000:1 scale. For low level navigation tasks, a substantially larger gaming area is required. A larger scale (1500:1 or 2000:1) to allow the low eye height for takeoff and landing would be of similar physical size but provide a much reduced gaming area. The modeling detail for the TMB should be commensurate with the overall visual system resolution to provide usable detail to the pilot. These features should include varied natural and cultural features such as airfields, conventional ranges and tactical targets.

Some visual feature is required to define the edge of the buffer zone near the mirrors to prevent unexpected zero visibility conditions while maneuvering around targets near the edges of the gaming area.

Suitable airfield, cultural, and conventional target lighting is required to provide a realistic night scene. Both nondirectional and directional lighting should be used, as appropriate, to represent real-world lighting characteristics, which prevent unnatural restrictions on pilot task performance.

Further research to improve the scaling techniques, terrain and target models, is required. Scale model boards on the order of 7000:1 are required allowing an employment concept of using a 1500:1 or 2000:1 board for takeoff and landing and transitioning to a 7000:1 board for conventional range and tactical work. This concept provides a much greater degree of flexibility over present day TMB's restrictions. Repetitive use of a model board would soon lead to excessive pilot familiarity, which would reduce task loading on the pilot. New concepts of model employment (i.e., changing inserts, overlaying targets with removable mountains, removing a dam to reveal a fortified position) must be explored to present a constant variety and complexity of target areas.

5. Weapons Effects and Scoring

Weapons effects, including ordnance impacts and tracer fire are required to provide visual feedback to the pilot. This feedback indicates the effectiveness of his weapons delivery and allows error analysis prior to the next delivery. This is especially important on the tactical range or for targets of opportunity which may not be designated for score.

Accurate weapons trajectory and scoring algorithms are required to properly compute and display weapons effects. It must be noted that weapons trajectory and scoring computations are normally performed in the host simulator computer, not the visual computer, and therefore, both computers form an essential part of any weapons delivery simulation.

(b) Required/Optimum Dome Display System Performance

1. Display

The FOV of the display should approximate that of the aircraft with normal aircraft restrictions such as canopy frames or aircraft surfaces. This would prevent artifical restrictions introduced by the visual display from altering task performance.

2. AOI Size

The size of the AOI must be substantially larger than the 60° diagonal AOI demonstrated to reduce the head motions required for orientation around the target area and during the weapons delivery. A larger AOI would enable a more realistic amount of head movement and thus allow a more proportionate amount of eye motion to be used for orientation. This would allow more normal concentration on the target and the weapons delivery with more realistic effort required for overall orientation. At this time, the required size of the AOI can not be estimated. No objective data exists to define its size.

The major problem with a large AOI is in the display, not the image generation area. Significant engineering development is required to allow projection of a high resolution, wide angle AOI in a dome display. The most promising solution would utilize multiple projectors to increase the AOI size.

3. AOI Mechanization

The AOI should be operated in a combination of head-slaved and target-slaved modes with an automatic transfer between them. This feature would allow the pilot to locate the target without revealing it to him as the geometric center of the AOI. He thus could freely maneuver about the target, roll-in, and then not have to make unnatural head movements to keep the target in the AOI. Following weapons release, the AOI would again become head slaved to prevent its disappearance beneath the aircraft.

The AOI must be accurately synchronized with the background horizon projected by the point light source sky/earth projector. Additionally, both horizons must smoothly track each other within the FOV to prevent disorientation.

4. Background Imagery

Background horizon and sky/earth imagery is required throughout the display FOV. It must support the AOI, yet provide sufficient peripheral attitude cues to be useful to the pilot. Limited heading cues are necessary and may be provided by mountains on the horizon. Currently, a point light source sky/earth projector using spherical transparencies provides the most satisfactory background imagery for a dome system, but lacks sufficient ground feature.

5. Color

Color imagery is desired for the AOI display. Color imagery provides an apparent resolution increase for the pilot over monochrome imagery with the same or degraded measured resolution. The use of color imagery as opposed to monochrome provides additional cues, thus allowing more rapid recognition of objects which are otherwise identical. The more natural recognition of objects allows the pilot to use more normal cues for task performance.

The problem associated with color in a TMB/Dome System lies primarily in the display. A color projector is fairly large and its physical size makes it hard to accommodate in a small dome without excessively restricting the FOV. Projector size becomes less of a restriction as the dome radius becomes larger. The weight of the projector is also a problem for the demonstrated five DOF beam motion system, but not for other types of motion systems. Continuous research efforts are required to develop a more compact, high resolution, high brightness color televison projector.

6. Day/Dusk/Night Capability

The display must be capable of presenting dusk and night lighting conditions in addition to daylight conditions. The projector must respond to low light levels with little loss of resolution and minimum lag to clearly present night scenes and lighting without streaking.

3. TMB/OPTICAL MOSAIC RESULTS

a. Technical Results

(1) Visual System Features

(a) Ground Terrain Display Format

The system displays AOI in a 40° by 40° format. A background earth/sky scene complemented the AOI format and was displayed throughout the remaining FOV.

(b) AOI Slew

The AOI could appear throughout the total display FOV.

(c) Concurrent Display

The system was capable of concurrently displaying the ground AOI, background terrain surrounding the AOI (a synthetic terrain), and a fixed reticle F-4 gunsight. The image of a second aircraft was not displayed for this project. Both schedule and technical constraints prevented this feature from being demonstrated.

(d) Mission Monitoring

The background terrain and the AOI were displayed at the control console on separate monitors. The AOI monitor could not display roll. Therefore, the display was limited in its usefulness to convey information to the instructor. Two graphic displays were available to pictorially present the aircraft flight path during the mission from any perspective. All pertinent flight parameters were simultaneously displayed.

(e) Weapon Delivery Scoring

The system was not capable of accurate weapon delivery scoring within the constraints of this project. Both insufficient time and integration problems prevented total debug of the scoring capability. Real-time display and hardcopy printout of scoring are medium risk additions to the system. Immediate visual feedback of impact is possible at medium risk.

(f) Ceiling and Visibility

No capability to simulate a ceiling was displayed during this project. Visibility was manually preset and was not calibrated to correspond to any particular distance. Visibility was controllable only in the synthetic terrain background and not used during this project. Due to schedule constraints, no provision was made to simulate limited visibility in the AOI.

(g) Moving Targets

This system included no means for simulating a moving target on the surface.

(2) Technical Performance Measurements

(a) Resolution

Limiting resolution was about 350 TV lines in the display. This is about 6.8 arc minutes which closely agrees with the curves for MTF (Reference Volume 2). MTF generally neared zero at seven to eight arc minutes.

(b) Scene Detail

No quantitative figure can be applied to the amount of scene detail in the model board image.

(c) Contrast

Constrast was highly dependent on how the system was adjusted. The most important adjustment appeared to be the pedestal level on the camera. Individual display window adjustments were also important. Using the camera video, contrast in window three was less than four; in window six, it was less than five. Using the gray scale from a pattern generation, contrast was from 30 to 35 in windows 2, 3, and 6. (Reference Figure II-11 for window numbering).

(d) Brightness

The brightest highlight measured in the small raster was 3.8 foot lamberts in window 3. The brightest gray shade on the STG was .7 foot lambert. The sky was about 1.2 foot lamberts.

(e) MTF

Static horizontal modulation transfer was over 30% at 10 arc minutes at the camera output. It dropped to 6-12% in the display depending on which window was observed. Window 6 was the best of windows 2, 3, and 6. Static vertical modulation transfer in the display ranged from 25-45% depending on which window was observed and where the reading was taken in the window. Modulation transfer decreased under dynamic conditions. The decrease is gradual, and 12 arc minutes resolution did not become unreadable until motion exceeded 25 degrees/sec.

(f) AOI Edge and Corner Resolutions

Limiting resolution near the AOI corners dropped off considerably. The loss was about 20% at point five degrees from each corner at the camera output. The loss was greater in the display and was dependent on position of the AOI within the window.

(g) Image Distortion

The display of a square linearity pattern measured about 35 degrees wide by 38 degrees high with the AOI centered in window 3. In order to separate this out-of-square characteristic from further calculations, the expected location for point within the distorted square was calculated. When this was done, a sampling of 16 points within the AOI all were within .5 degrees of where they should be. Eleven of the sixteen were within .2 degrees of where they should be. Thus, linearity was excellent and the only distortion of any consequence with the AOI centered in the window was a scaling difference of less than 10% between the vertical and horizontal axes. Distortion near the joints was much more serious and took three general forms:

1. Displacement Across the Joint

One point was observed simultaneously in two adjacent windows with over three degrees difference in the viewing angles. This appeared to be a worst-case observation.

2. Direction Change Across the Joint

Between windows 2 and 3 near the 2-3-6 tri-joint, straight lines changed direction by about 11 degrees.

3. Bowing

One line in window 6 near the 2-3-6 tri-joint, became bowed enough to change direction by 20 degrees from one end to the other.

All of the above distortions were strongly effected by AOI position and AOI rotation.

(h) Variation of Brightness

Brightness variations in the display were relatively minor. One small area in the lower left corner of window 2 was noticeably less bright than its surroundings. The lower right corner of the AOI was noticeably brighter than the rest of the AOI regardless of AOI position.

(i) Collimination errors

All sampled points appeared at infinity or nearer than infinity. The worst sampled point in window 3 appeared at about 115 feet (6.9 arc minutes).

b. Operational Results

The results of the TMB/Optical Mosaic system evaluated are presented in four sections identical to the previous technologies discussed.

(1) Demonstrated Capabilities and Average Ratings

Ratings and comments are listed in this section.

(a) The 81 tasks which were performed during the Phase II evaluation are listed in Table III-10. The pilots were asked to rate each task with regards to the capability of the device to allow performance of the task.

The task ratings for the TMB/Optical Mosaic system evaluated were low in many cases and 20 of the 81 project tasks could not be accomplished due to system limitations and anomalies due primarily to the scope of the project and importance of the weaponry tasks.

This technology supported performance of departure, approach, and low approach tasking as well as aerobatics and general airwork. The low scores that were obtained in these areas can be accredited to the small, disjointed AOI and lack of image clarity.

The pilots could perform weaponry roll-ins and deliveries, but in many cases, had to alter their normal procedures and develop new techniques in these areas due to system limitations.

Low angle weaponry was possible, but high angle was restricted by the pitch limit on the probe.

TASK TITLE	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVI-TION	PILOT/PROJECT MANAGER REMARKS
TAKEOFF	0	NOT ACCOMPLISHED - NO LANDING GEAR OR FLAPS				
NIGHT TAKEOFF	0	NOT ACCOMPLISHED - NO LANDING GEAR OR FLAPS				
DEPARTURE	16	2.9	3	3	.68	
NIGHT DEPARTURE	6	2.2	2	2	.75	
STRAIGHT IN	13	2.7	3	3	.95	Lack of Detail - Altitude cues difficult.
NIGHT STRAIGHT IN	6	2.0	2	1,2,3	.89	Inadequate night lighting
RADAR FINAL APPROACH	0	NOT ACCOMPLISHED - NO MONITOR CAPABILITY				
VFR OVERHEAD	16	2.6	3	3	.51	Limited gaming area.
NIGHT VFR OVERHEAD	6	1.8	2	2	.41	Gaming area and night landing.
GLIDE PATH CONTROL	17	2.5	2	2	.87	Limited visual cues.
NIGHT GLIDE PATH CONTROL	6	2.0	2	1,2,3	.89	
GO AROUND	16	2.9	3	3	.68	
NIGHT GO AROUND	6	2.2	2	2	.75	
CLOSED	15	2.6	3	3	.63	Ground track cues difficult
NIGHT CLOSED	6	2.0	2	2	.63	Inadequate night scene.
REENTRY	13	2.3	2	2	.85	Small AOI limiting.
NIGHT REENTRY	6	2.0	2	2	.63	Insufficient night cues.
LOW APPROACH	30	2.6	3	3	.90	Limited image clarity.
NIGHT LOW APPROACH	12	2.0	2	1,2,3	.85	
TOUCH AND GO LANDING	0	NOT ACCOMPLISHED - NO LANDING GEAR OR FLAPS				
NIGHT TOUCH & GO LANDING	0	NOT ACCOMPLISHED - NO LANDING GEAR OR FLAPS				
FULL STOP LANDING	0	NOT ACCOMPLISHED - NO LANDING GEAR OR FLAPS				
NIGHT FULL STOP LANDING	0	NOT ACCOMPLISHED - NO LANDING GEAR OR FLAPS				
LAZY EIGHT	6	3.7	4	4	.52	STG beneficial
CHANDELLE	6	3.7	4	4	.52	STG beneficial
SLOW FLIGHT	5	3.0	3	3	.71	Limited FOV.
STALLS	6	3.5	3.5	3,4	.55	
VERTICAL RECOVERY	6	4.2	4	4	.75	
SPINS	12	4.6	5	5	.67	STG and horizon beneficial.
AILERON ROLL	6	3.8	4	4	.75	
BARREL ROLL	6	3.8	4	4	.98	
CLOVERLEAF	5	3.6	4	4	.55	
LOOP	6	3.7	4	4	.52	STG beneficial.
IMMELMANN	6	3.7	4	4	.52	Good lineup cues.
SPLIT S	6	3.5	3.5	3,4	.55	
CUBAN 8	6	3.7	4	4	.52	

TABLE III-10 - TASK ACCOMPLISHMENT AND RATING (TMB/OPTICAL MOSAIC)

TASK TITLE	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVIATION	PILOT/PROJECT MANAGER REMARKS
FORMATION TAKEOFF	0	NOT ACCOMPLISHED - NO NEAR FORMATION CAPABILITY				
CLOSE FORMATION	0	NOT ACCOMPLISHED - NO NEAR FORMATION CAPABILITY				
ROUTE FORMATION	0	NOT ACCOMPLISHED - NO NEAR FORMATION CAPABILITY				
CROSS UNDER	0	NOT ACCOMPLISHED - NO NEAR FORMATION CAPABILITY				
CLOSE TRAIL	6	3.2	3.5	4	1.47	
EXTENDED TRAIL	16	4.4	4.5	5	.72	
TACTICAL FORMATION	12	4.3	4	4	.65	
FORMATION LANDING	0	NOT ACCOMPLISHED - NO NEAR FORMATION CAPABILITY				
BOX PATTERN	30	2.9	3	3	.45	Ground track cues difficult.
NIGHT BOX PATTERN	6	2.3	2	2	.52	Incorrect night lighting.
ROLL IN	30	3.3	3	3	.52	Channel cross distracting.
NIGHT ROLL IN	42	2.7	3	3	.61	
DIVE ANGLE ESTABLISHMENT	36	3.2	3	3	.58	Limited visual cues.
NIGHT DIVE ANGLE ESTABLISHMENT	42	2.7	3	3	.54	
RECOVERY	36	3.4	3	3,4	.60	Over reliance on instruments.
NIGHT RECOVERY	41	2.8	3	3	.77	
LOW LEVEL BOMB	0	NOT ACCOMPLISHED - MINIMUM ALTITUDE LIMIT ON PROBE				
LOW ANGLE STRAFE	18	3.1	3	3	.73	Limited detail.
NIGHT LOW ANGLE STRAFE	6	2.3	2	2	.52	
10 DEGREE SKIP BOMB	18	2.9	3	3	.80	Limited detail.
15 DEGREE LOW ANGLE BOMB	17	3.2	3	3	.57	Limited detail.
NIGHT 15 DEGREE LOW ANGLE BOMB	12	2.3	2	2	.45	
20 DEGREE LOW ANGLE LOW DRAG BOMB	18	3.2	3	3	.65	
NIGHT 20 DEGREE LOW ANGLE LOW DRAG BOMB	6	2.3	2	2	.52	
30 DEGREE DIVE BOMB	18	3.2	3	3	.62	
30 DEGREE HIGH ANGLE STRAFE	18	3.2	3	3	.65	
45 DEGREE DIVE BOMB	18	3.2	3	3	.62	Restrictive pitch limit.
45 DEGREE HIGH ALTITUDE DIVE BOMB	17	3.1	3	3	.66	Restrictive pitch limit
60 DEGREE DIVE BOMB	0	NOT ACCOMPLISHED - PITCH LIMIT ON PROBE				
LOW LEVEL NAVIGATION	0	NOT ACCOMPLISHED - SMALL GAMING AREA AND TARGET FIXED AOI				

TABLE III-10 (CONTINUED)

TASK TITLE	SAMPLE QTY	MEAN	MEDIAN	MODE	STD DEVIATION	PILOT/PROJECT MANAGER REMARKS
ARMED RECONNAISSANCE	6	1.7	1	1	1.21	
ATTACK WITH FORWARD AIR CONTROLLER	0	NOT ACCOMPLISHED - MINIMUM FORMATION CAPABILITY				
KEEPING FORWARD AIR CONTROLLER IN SIGHT	0	NOT ACCOMPLISHED - MINIMUM FORMATION CAPABILITY				
MUTUAL SUPPORT ATTACK	6	4.0	4	4	1.00	
LOCATE TARGET	24	3.0	3	2	1.33	Tactical areas vague.
IDENTIFY TARGET	23	2.8	2	2	1.30	Photo mosaic inadequate.
ORIENT TO TARGET	30	2.7	3	2,3	1.31	Restrictive AOI size.
RESTRICTED PATTERN	6	3.0	3	2,3,4	.89	
RANDOM PATTERN	12	3.2	3	3,4	.94	Restrictive AOI size.
TERRAIN MASKING PATTERN	0	NOT ACCOMPLISHED - LACK OF APPROPRIATE MODEL.				
POP UP PATTERN	11	2.1	2	2	.93	Difficult orienting to target.
CURVILINEAR APPROACH	11	2.6	2	2	1.03	
MOVING TARGET ATTACK	0	NOT ACCOMPLISHED - MOVING MODEL NOT AVAILABLE				
ORDNANCE ADJUSTMENT	0	NOT ACCOMPLISHED - NO FAC OPERATIONS OR VISIBLE WEAPON IMPACT.				
REATTACK	6	2.5	3	3	.84	Limited AOI and target-slaved distracting.

TABLE III-10 (CONTINUED)

CUE	SAMPLE QUANTITY	MEAN RATING
ATTITUDE	503	3.518
DIRECTION	451	3.137
SPEED	509	3.132
ALTITUDE	509	2.905
DISTANCE	440	2.757
LOCATION	499	2.764
LINEUP	505	3.055

TABLE III-11 - SPATIAL ORIENTATION CUE RATINGS (TMB/OPTICAL MOSAIC)

CHARACTERISTIC	SAMPLE QUANTITY	MEAN RATING
SIZE	124	3.468
SHAPE	124	3.443
DETAIL	124	2.694
CLARITY	124	2.573
MOVEMENT	112	3.366
POSITION	118	3.483
ENVIRONMENT	124	3.073

TABLE III-12 - SPECIFIC REFERENCE CHARACTERISTIC RATINGS (TMB/OPTICAL MOSAIC)

TOPIC	SAMPLE QUANTITY	MEAN RATING
FOV	511	4.127
IMAGERY ALIGNMENT	60	2.78
IMAGE RESOLUTION	60	2.43
GAMING AREA	6	1.50
VISUAL SCENE ADEQUACY	186	2.7261
REAL-WORLD COMPLEXITY	12	3.4167
METEOROLOGICAL CONDITIONS	---	NOT AVAILABLE

TABLE III-13 - ASSOCIATED RATINGS (TMB/OPTICAL MOSAIC)

Tactical area operations were attainable but severely restricted by numerous display and generation limitations.

(b) Spatial Orientation Cue Analysis

Ratings for the spatial orientation cues are listed in Table III-11. Ratings vary from below good to near very good.

Pilots had little difficulty determining their attitude in this device due to the checkerboard background environment. Altitude, distance, and location cues were difficult to obtain due to the lack of information available in the AOI.

(c) Specific Reference Characteristic Ratings

The characteristics of selected items, objects, and features located within the visual scene were rated and are listed in Table III-12.

The size and shape of objects were generally rated high as was their position in the environment and relative movement. On the other hand, item detail and clarity were rated low due to the photo mosaic portion of the model board and the various display limitations.

(d) Associated Ratings

Associated topics were rated and appear in Table III-13. This device's FOV was rated high. The good rating for real-world complexity comes partially from the task loading that was added due to systems limitations, and not due to faithful replication of real-world situations.

The gaming area of the TMB was known to be limited in size and received a corresponding rating. Imagery adequacy, alignment and resolution problems are thoroughly outlined in the following section.

Supplementary motion, G-seat, G-suit, and auditory cues were not evaluated during Phase II operations due to the scope of this visual generation and display project.

(2) Limitations, Anomalies, and Improvements

(a) Image Generation

1. Edge Blanking Technique

The model board's maneuvering area was bordered by a buffer zone that was designed to restrict probe movement and prevent probe contact with the mirrored edges of the model board. When the aircraft crossed the boundary between the maneuvering area and the buffer zone, the AOI would disappear. Since the pilot could not visually determine the location of the buffer zone boundary, inadvertent flight too close to the model board edges resulted in unexpected and abrupt loss of the AOI imagery. This sudden edge blanking was unrealistic, distracting, and altered task performance.

a. Proposed Technical Improvement

Model board edge video blanking is inherent in any terrain model image generation system. When the model board imagery is properly located and scaled, pilot contact with board edges is minimized to the point where this (gaming area) limitation does not detract from the training effectiveness of the system. Time constraints necessitated model board modifications to be performed in such a way as to minimize the effort required. A properly designed and scaled model should meet user gaming area requirements without adverse effects from board edge blanking. Another approach to minimize the edge blanking problem is to define the edge of the buffer zone with natural or man-made features and to use them as if they were the boundaries of a range or restricted area and operate inside the boundaries. Risk is low.

b. Estimate of Proposed Improvement

Defining the edges of the buffer zone on a properly scaled and designed terrain board would prevent unexpected encounters with edge blanking and the subsequent task alteration.

2. Gaming Area

The 1500:1 scale TMB gaming area (approximately 3.5 X 7 NM) was too small for tactical weaponry or traffic pattern operations. The limited dimensions of the board caused numerous encounters with the edge blanking system and resulting loss of the AOI imagery. The 4000:1 scale TMB gaming area (approximately 9 X 10.5 NM) was also too small for tactical weaponry operations. The pilots were forced to substitute instrument readings and references to the background scene (Synthetic Terrain Generator grid pattern and markers) for normal visual cues that would have been available if the edge blanking system could have been avoided. This unnatural procedure altered task performance and distracted the pilots.

a. Proposed Technical Improvement

Proper selection of terrain model board size and scale and the proper location of target areas and airfields can provide an operating area suitable for most tasks and minimize encounters with the edge blanking system and the subsequent loss of terrain imagery. The size of the gaming area must be determined by the user for the tasks to be performed. Terrain model boards of areas as large as 20 X 105 feet have been built. The size of the model board is limited by the size of the facility, not by technology. At a 5000:1 scale factor this would represent a gaming area approximately 17 X 87 nautical miles. Risk is low.

b. Estimate of Proposed Improvement

A terrain model board, as discussed in the proposed solution, may provide a large enough gaming area to allow most tasks to be performed without unnatural restrictions.

3. Simulated weather and wind

Due to time and fiscal constraints, simulated weather and wind conditions were not available in this visual system. Realistic simulation of these features will be required in any future procurement effort intended for air-to-ground application.

a. Proposed Technical Improvement

Simulation of fog, reduced visibility, haze, and wind effects are state-of-the-art in visual simulation.

b. Estimate of Proposed Improvement

The simulation of wind and weather is state of the art and will provide an increased capability for training.

4. Night Lighting

The night scene presented by this visual system was generally too dark to allow normal night operations. There was not enough lighting detail around the airfield complex to provide the proper depth perception cuing. In addition, the airfield complex appeared as a group of overly bright lights from a distance instead of a network of runways and taxiways. The combination of these lighting limitations made night task performance extremely difficult.

The night scene appeared extremely grainy and blurred with rapid lateral or vertical AOI movement.

Target or runway identification was impossible when the AOI totally washed out during aircraft turns and subsequent AOI transitions.

The already dark night scene darkened more as the aircraft descended below 500 feet AGL which further increased the difficulty of performing night approach and weaponry tasks.

a. Proposed Technical Improvement

This model board's night lighting system was not representative of the SOA for terrain model night simulation. Although computer-generated techniques offer greater night light detail at lower cost than that associated with model board techniques, acceptable night lighting of runway complexes and urban areas has been demonstrated as SOA. The Project 2235 system integration was not optimized for night simulation.

Picture noise (grain) is attributed to action of the camera automatic gain control circuit acting on a low light level screen.

Image lag discussed was likewise caused by system operation at very low light levels.

Ambient lighting (model house enclosure ceiling lighting) was used for night model illumination. The airfield lighting is both highly directional, and poorly aligned. Thus, most airfield lights were not visible to pilots operating at low altitudes. All of the above deficiencies are correctable and regarded as SOA in visual simulation.

b. Estimate of Proposed Improvement

Proper night lighting and a stable, in focus AOI at night appear to be SOA. The addition of these improvements would greatly improve system utility for night approach and weaponry tasks.

5. Probe Limits

The probes viewing direction depended on the target's location and the aircraft's horizontal and vertical distance from the target. As the aircraft approached a selected target in level flight, the probe's pitch angle increased in order to keep the AOI centered on that target. As the probe's angle reached approached 50 to 60 degrees, the bottom portion of the AOI would increasingly darken. During the performance of steep weaponry deliveries coupled with large release mil settings, this darkening effect covered the target area and made further task performance impossible. At other times, the lower AOI darkening was simply annoying.

In order to protect the probe from inadvertent contact with the model board surface and resulting probe damage, a software limit was placed on the probe's vertical travel. This software program restricted the aircraft to various minimum altitudes depending on the aircraft's location on the TMB. However, the actual aircraft altitude, as represented on the altimeter, continued to decrease when the aircraft encountered one of these areas of restricted maneuvering. When the aircraft subsequently flew out of the limited area, it abruptly descended visually to the altitude indicated on the altimeter. This probe protection system therefore casued a very distracting loss of altitude which severely altered task performance. This feature was considered as a possible contributor to negative training since the pilots became accustomed to rapid, unsolicited descents which were terminated by the computer and not by their actions.

a. Proposed Technical Improvement

The design of the probe used for this evaluation was not capable of pitch down performance exceeding 50°. Camera probes capable of a 90° pitch down are SOA in visual simulation. Correction of the deficiency can be achieved through purchase of such a probe having a pitch prism capable of the 90° pitch down. The deficiencies noted are a direct result of the probe crash protection system used (software protects). Other probe crash prote tion techniques have been developed and demonstrated which do not require altitude restrictive programming. Such systems have been demonstrated and are SOA.

b. Estimate of Proposed Improvement

A probe with a 90° pitch down capability would allow steeper dive angles and looking at targets directly below the aircraft's flight path and remove this task limitation. The use of a probe crash protection system allowing the probe to descend to lower altitudes would remove the discrepancy between visual aircraft altitude caused by probe limits. This should eliminate a condition causing possible negative training for appropriate tasks.

6. Synthetic Terrain Generator (STG)

Although the STG provided a much better background than a more austere earth/sky projection system, there were still several limitations which would have to be overcome before this technique would be suitable for use in air-to-ground operations.

The STG did not provide low altitude cues below approximately 400 to 500 feet.

The lack of cultural references, three dimensional objects, or low altitude detail made flying at low altitudes impossible without reference to cockpit indications.

The location of primary model board imagery, such as runways, bomb circles, or selected tactical targets, should be identified and correlated in the STG so that visual navigation around an airfield or target complex could be performed during operations without AOI imagery.

The AOI appeared as a floating, suspended unit of imagery above the plane of the STG. In addition, there was an apparent relative motion between the edges of the AOI and the bordering grid pattern of the STG. The resulting change in alignment of the AOI and STG imagery created the tendency for the pilots to become misaligned with particular references and detect that the aircraft's heading was slowly changing when, in fact, it was remaining constant. The floating effect and turning moment was confusing and altered task performance.

a. Proposed Technical Improvement

The Synthetic Terrain Generation system was design for moderate to high altitude operation in air-to-air combat environment. It represents a low cost approach which is incapable of providing low altitude detail cues, cultural information, or three-dimensional objects. Upgrade of the STG to provide these cues amounts to the development of the conventional computer generated display. The latter is SOA.

Correlation of STG symbols with AOI imagery targets is feasible. Risk is Low. Precise registration of the edges of the STG with AOI features is not practically possible. If a simple CIG system were used for ground references, registration is feasible. Risk is medium.

b. Estimate of Proposed Improvement

It appears that the STG would be better replaced with a CIG system if very low altitude cues, cultural information, and three-dimensional objects are required. The STG symbols can be correlated with AOI targets to provide additional references for target location. A simple CIG terrain appears to be required if precise registration of the AOI with the terrain is required.

7. Aircraft Drift

A significant right to left aircraft drift was apparent approximately 30 percent of the time throughout this evaluation. This lateral drift was similar to a strong crosswind even though a crosswind was not intended. The pilots reacted to this condition as if if was a crosswind and therefore were not distracted. However, this system anomaly would be confusing if variable winds could have been selected.

a. Proposed Technical Improvement

The drift condition reported by the pilots was found to be caused by slippage in the coupling mechanism of one of the probe's servo synchros. This problem was corrected. Drift seen on dive passes can also be attributed to misalignment of the probe to the gantry/model. This problem can be corrected.

b. Estimate of Proposed Improvement

These solutions should remove the unwanted drift and must be accomplished on any similar visual system to allow weapons delivery tasks to be performed normally.

8. Target Slaved AOI Control

Operations with the AOI centered on selected items resulted in several limitations or distractions. If the target to be attacked was the same item that the AOI was centered on, then it was too easy to locate that target (assuming a clear display) since the AOI center was easy to determine. If the target to be attacked was not at the center of the AOI, then, as the aircraft would approach the target, the camera probe would continue pointing at the AOI center which resulted in attacking targets that would appear at a vertical or horizontal edge of the AOI. The AOI would steadily move left, right, up, or down in an attempt to stay centered on its preselected center, which was not the current target. The pilot would interpret this AOI movement as a drift in the aircraft's ground track (this drift is different than that mentioned above). Accordingly, attacking targets that were not at the center of the AOI was very confusing, distracting, and difficult.

a. Proposed Technical Improvement

Operation of an AOI system in the target slaved mode presumes that the target is located in the center of the AOI; placement of the target of interest elsewhere within the AOI will predictably yield the deficiency addressed. A system is feasible wherein the target of interest would be randomly moved about the AOI. Psycho-physical effects of this approach are unknown. Risk of implementation is medium.

b. Estimate of Proposed Improvement

If random motion of the target of interest in the AOI was used, the AOI would not point out the target but the problems of attacking a target off center in the AOI would remain.

9. Photo Mosaic

The photo mosaic was considered totally inadequate for use in obtaining aircraft spatial orientation cues or recognizing specific references. Only those items that were enhanced with three-dimensional construction were usable as specific references. The remainder of the mosaic detail was totally unrecognizable at reasonable distances.

a. Proposed Technical Improvement

Use of a photo mosaic was an unsuccessful experiment. The composite resolution of the system was incapable of displaying the high level of detail available in the mosaic. In retrospect, lower resolution, enhanced, artificial imagery would have been more appropriate for this system application.

b. Estimate of Proposed Improvement

Concur.

(b) Image Display

1. AOI Size

Model board imagery was displayed in a 40 by 40 degree AOI surrounded by a grid pattern background. Since the grid pattern was composed of several markers and many squares of varying tones, aircraft direction, distance, location, and lineup cues, as well as the target's position, could partially be obtained from a combination of the imagery within the AOI and the background. Notwithstanding the visual support that the background grid pattern supplied, the size of the AOI was still considered inadequate for allowing unaltered task performance. It was difficult to determine precise aircraft position when operating in a target area due to the restricted viewing area of the small AOI. Performance of traffic pattern and weaponry tasks was altered due to the lack of total airfield or target area viewing and resultant dependency on attaining cues from cockpit indications.

a. Proposed Technical Improvement

Presentation of an AOI greater than 40° X 40° prohibits the use of the display's small raster. Larger AOIs cannot be presented by the small (shrinkable) raster due to deflection amplifier constraints. The AOI must be displayed as a part of the background image. The dual raster system could be retained for presentation of target images. However, the AOI imagery would then be displayed with the inherent low resolution of the background raster. If the dual raster scan is replaced with a single raster display, all scan lines could be devoted to presentation of the background image with the AOI inset in the video. However, use of insetting techniques required multiple image generation sources to provide the image to each of the windows used as the AOI crosses the display tri-joint. Each window will require a section of properly aligned imagery derived from the integrated AOI image. If the AOI is restricted to 40°, three sources (for one tri-joint) are required. If the AOI approaches 120°, six sources are required. Technical problems associated with derivation of the six channels of information from a camera/model analog video image generator are so complex as to be impractical. A CIG image having six channels could be procured more easily and more cost effectively.

Model board image generation for fields of view up to approximately 80° is within current technology. Systems with a wider AOI have been developed, although not completely successfully. Use of a camera/model board image with AOIs greater than 40° presents severe problems if integrated with a mosaic-type display, in that a dynamic, multichannel image is required (one channel for each window in the AOI at only one time). Cost and complexity of a multichannel system make this approach unpromising compared with CIG approaches.

b. Estimate of Proposed Improvement

It appears that the display is the limiting factor for the AOI and the responses indicates that it does not appear practical to expand the size of the AOI using terrain model board imagery due to complex technical problems. This places a severe limitation on the CRT Mosaic/Terrain Model Board Configuration to perform air-to-ground tasks. A CIG image can be used with this display quite successfully, however, and appears a more satisfactory solution.

2. AOI Frame

The rectangular shape of the AOI occasionally induced an artificial bank or pitch sensation. Several of the pilots considered this feature distracting because of the attitude corrections which they introduced in response to the false visual cue.

The AOI frame, which was rectangular when the AOI was all in one window, became very disjointed as the AOI crossed window seams. This was very distracting since the frame would be in continual state of change between windows.

a. Proposed Technical Improvement

AOI edge frame effects can be reduced or eliminated in two ways. First, the AOI could be made circular. The harshness of the edge would be still apparent, but use of the edge for references would be eliminated. Secondly, the image could be made to blend gradually into the STG. This approach would result in a blur zone surrounding the AOI.

Disjointed edges crossing the tri-joint are a direct result of pancake window/CRT mapping errors. Correction of these errors (to reasonable tolerances) is within the SOA and low risk.

b. Estimate of Proposed Improvements

A blended, circular AOI would eliminate the use of a straight edge as a pitch or bank cue. AOI distortion or bending when crossing a window seam can evidently be reduced but not removed.

3. Field of View and Pancake Window Positioning

The vertical field of view on the left and right side of the cockpit was somewhat limiting due to the position of number one, two, four, and five video channels. Those channels did not visually extend below the canopy rails and therefore created a dark gap between the bottom of the video presentation and the top of the cockpit interior. Since the bottom of the video channels was slanted (i.e., not horizontally level), several pilots indicated that they were experiencing difficulty maintaining level flight when observing AOI or background imagery in the lower portion of those lateral windows.

As a result of this evaluation, it was determined that the tri-joint between windows appeared to be located in a very distracting position. The ten-thirty area was the vicinity that a tactical target was positioned for the majority of a random attack pattern and curvilinear approach. Since these types of patterns and approaches were used exclusively during tactical operations, and since the ten-thirty area is a tri-joint location, the tasks of target acquisition, identification, and alignment were continually compounded by the imagery mismatch inherent in a tri-joint area.

a. Proposed Technical Improvement

Orientation of the SAAC dodecahedron display structure was optimized for the air-to-air combat application. This orientation resulted in the location of dead zones along the canopy rails, and tri-joints at a point in the FOV normally used for air-to-ground imagery. Reorientation of the display structure to minimize effects of the mosaic structure on the principle training task is possible. This amounts to a design problem unique to each aircraft and its primary mission. Risk associated with reorienting the dodecahedron is low. Risk associated with redesign of the display (other than dodecahedron) is medium.

b. Estimate of Proposed Improvement

A reorientation of the display should minimize the effect on tactical deliveries.

4. Image Identification

It was difficult to determine the identification of many images within the AOI for several reasons. The AOI imagery was not in sharp focus. Many images appeared hazy, fuzzy, or blurred. Image clarity within a given window also varied from day to day. Consequently, target identification and tracking was much more difficult than is normally expected and task performance was altered since the pilots attempted to maneuver the aircraft in order to keep an image in the clearest window for the maximum amount of time.

The monochrome display with its limited shading capability did not enhance the effective resolution as might be expected from a color display.

a. Proposed Technical Improvement

AOI image quality (resolution) resulting from the Project 2235 integration was considerably less than desired. Resolution deficiencies are attributed to poor display window electronic focus alignment, display resolution limitations (by design), and camera resolution limitations when integrated with the scanning mode.

Display window focus alignment is correctable within SOA. The ultimate display resolution capability is currently limited by the particular dual raster scanning system used in the visual display. The system was designed for optimum resolution of target aircraft images at long range. Resolution of large images at close ranges (represented by the small raster operating in the 40° by 40° AOI mode) was compromised in deference to far range performance. Significant improvement of display (only) performance is not possible if the dual raster system is retained. Camera performance was degraded significantly due to the system constraint that required its scan timing be locked to the display system. This results in unusually high image tube writing speeds which are fundamentally incompatible with the physics of the image tubes used. The camera problem is correctable at moderate risk through development of a specialized camera designed to perform at the high writing rates. However, significant improvement in the integrated system performance is not expected unless the scan timing is changed to reduce the active scan writing speed. This would require decreasing the system retract time.

This amounts to performance beyond the capabilities of the display deflection amplifiers. New amplifiers could be developed at medium to high risk.

b. Estimate of Proposed Improvement

Having been optimized for long range performance, changes to these limitations would be costly, time-consuming, and doubtful as to degree of improvement.

5. AOI Erratic Movement, Window Blinking, and Imagery Alignment

The AOI occasionally jittered, jumped, or changed size throughout the evaluation of this visual system. When any of these erratic movements occurred, task performance was momentarily interrupted.

Several of the mosaicked windows occasionally blinked out and back on during the evaluation. Depending on the duration of the window-out condition, this anomaly was either distracting or terminated task performance.

Imagery alignment between some windows, as observed during moments of imagery channel cross, was extremely distorted. At certain channel seams, the imagery would be distorted as much as twenty degrees, which would appear as a bend in a particular runway, road, or weaponry run-in line. In a similar fashion, imagery would occasionally double or triple in quantity as it crossed a seam or tri-joint area. Target acquisition, identification, and tracking was very difficult since several targets and run-in headings were available as a result of the confusing window alignments.

a. Proposed Technical Improvement

Erratic movement of the AOI and window blinking effects were caused by computer processing problems. These problems are correctable within SOA. Mosaic display mapping is correctable within the SOA. The imagery alignment problems between windows was caused by display mapping errors.

b. Estimate of Proposed Improvement

The proposed improvements would appear to satisfy the limitations and anomalies.

(c) Other Simulator Features

1. Motion Platform

The motion system appeared to lag behind the anticipated movement of the simulator as forecasted by the pilots. This lag would cause pilot-induced oscillations during recoveries from weaponry passes or any high speed dives. A similar lag in the roll axis appeared to be present.

a. Proposed Technical Improvement

Motion system lags are principally due to insufficient bandwidth in the motion system hardware. Some fault may also lie in the low computation iteration rate used. It is expected that motion system performance (lag) could be improved considerably (not fixed) if the above areas were improved. Hardware bandwidth can be improved at moderate risk. Higher computation iteration rates can be provided within the state of the art.

b. Estimate of Proposed Improvement

It should significantly improve motion system lags.

2. Scoring

Accurate scoring on this system was not achieved during the evaluation. Establishment and proof of a scoring system accurate to approximately five mils would be required on any future procurement designed for air-to-ground application.

a. Proposed Technical Improvement

Time and fiscal constraints precluded development of an accurate scoring system. Technical deficiencies included the following: misalignment of camera probe to the gantry/model; camera deflection system drift; probe roll run-out errors; computational data transfer time lag; and inaccuracies in scoring computation.

Scoring performance can be drastically improved within SOA through efforts to align the camera, reduce the probe roll runout, and eliminate extraneous computers from the scoring loop. Correction of the scoring system to levels required (five mils) can be accomplished at medium risk.

b. Estimate of Proposed Improvement

Accurate scoring is a positive reinforcement to proper error analysis and a mandatory requirement.

3. Aircraft Flight Dynamics

The simulated aircraft appeared to be unstable and oversensitive about the pitch axis.

a. Proposed Technical Improvement

Pitch instability problems are attributed to the following: a computational iteration rate that is too low; a poor control loading system having insufficient bandwidth; and a marginal or insufficient aero flight data.

All of the above deficiencies are correctable within the state of the art.

b. Estimate of Proposed Improvement

Concur.

4. G-Seat/Suit System

G-seat and suit inputs appeared to lag that anticipated by the pilots. The inflation and deflation rates appeared to be too slow. The G-seat seemed to apply pressure unevenly in instances where the pilots felt that the pressure inputs should have been smooth and evenly distributed. The G-seat cue for afterburner power appeared unrealistic to several of the pilots.

a. Proposed Technical Improvement

G-seat/suit lags are directly attributable to hardware design. Lags noted are inherent to the pneumatic valves used. Correction of this deficiency will require complete redesign of the seat. Risk is medium. G-seat cue quality is primarily a function of programming. The G-seat was designed for maximum flexibility to support research and development of seat programming. Very little needed research has been accomplished. Efforts have been recently initiated to define G-seat programming requirements. Risk of success is medium.

b. Estimate of Proposed Improvement

Further research and development will hopefully help alleviate the limitation.

(3) Significant Strengths

(a) Field of View

The system has excellent horizontal and vertical FOV for all tasks performed.

(b) Formation and Air-to-Air

This was an excellent system which is optimized for air-to-air combat. It was easy to maintain visual contact and determine the other aircraft's attitude, orientation, and speed during the special air-to-air sortie provided after Phase II completion. There was very good system alignment in the air-to-air mode. In the air-to-air mode the system demonstrated very good resolution. System design permitted accurate formation flight beyond the route formation position.

(c) Visual Blackout

The dimming of the visual displays at high G provides a very good G cue.

(d) Synthetic Terrain Generator (STG)

The synthetic terrain assumed increased importance because of the target-slaved AOI which restricted the detailed visual scene to the immediate target area. At times it was the only reference available for attitude and orientation cues due to the aircraft's position relative to the AOI, e.g., recovery from a weapons pass after overflying the AOI. Other aids to orientation included geographically referenced noncultural symbology (e.g., a small square or cross within a grid square) in addition to a dull glowing circle in the eastern sky - the sun. The horizon and grid square pattern of the synthetic terrain provided good attitude, speed, and altitude cues down to approximately 400 to 500 feet.

(4) Required/Optimized System Performance Characteristics and Potential Capabilities (TMB/Optical Mosaic)

This section combines the demonstrated capabilities, significant strengths, and proposed technical improvements into an optimized TMB image generator and optical mosaic display system. It is important to remember that this optimized system is a departure from the system evaluated and the data collected during Phase II. Optimized characteristics that are not SOA are identified by the need for research. Inherent systems features are not listed, as previously explained.

(b) Required/Optimized Optical Mosaic Display System Performance

1. Field of View

The FOV of the display, with head movement, must closely match that of the aircraft to be simulated to allow the target to migrate within the FOV as in the aircraft. This is essential to prevent abnormal task performance. Normal aircraft visual restrictions such as canopy frames and aircraft surfaces are essential. Some of the tasks requiring the full FOV include: air scoring, SAM evasion, recovery from a weapons delivery, normal target placement during high and low angle bomb, strafe, tactical weapons deliveries, reattacks on tactical targets, and closed and overhead patterns.

2. AOI Size

The size of the AOI must be substantially larger than the 40° diagonal AOI demonstrated to eliminate the excessive head motions associated with a 40% AOI. A larger AOI would allow more eye motion to be used for orientation instead of requiring head motion. This would allow more normal concentration on the target and the weapon delivery with more normal effort required for overall orientation. At present the actual required size of the AOI can only be estimated. No objective data exists to define the size.

Current technology does not practically permit a large, high resolution AOI to be displayed in a CRT optical mosaic display system. Research and development may provide a practical method for display of such an AOI but the solution is complex, not near term, and high risk.

3. AOI Mechanization

The AOI should be operated in a combination of head-slaved and target-slaved modes with an automatic transfer between them. This would allow the pilot to locate the target without the AOI pointing it out to him, maneuver about the target freely, and then after roll-in, not have to be concerned about head movements to keep the target in the AOI. After weapons release, the AOI would again become head slaved to prevent its disappearance below the vertical FOV limits.

4. Display Orientation

Optimum display configuration and display orientation is essential for each aircraft type. This optimization is essential to maximize the usable FOV and to keep window joints and tri-joints away from critical viewing areas (i.e., the high 10 o'clock position where a target is placed during a curvilinear weapons delivery).

5. Displayed Image Distortion

Images displayed dynamically must be clearly adjacent and exhibit minimal distortion when tracking across window joints or tri-joints to assure task performance continuity. For example, low angle strafe on a controlled range where continuous alignment and position judgments are required and during roll-in and curvilinear patterns is especially critical. Some additional development may be required in this area to minimize distortions near display window joints.

6. Display Image Resolution

Displayed image resolution must be optimized to the maximum extent practical. Resolution on the order of 6 to 7 arc minutes is SOA with present single raster displays and is sufficient for most air-to-ground tasks.

A resolution of approximately 1-2 arc minutes is estimated to be required for airborne or small ground targets. A shrinkable dual raster display can provide the approximate 1-2 arc minute resolution, but the resolution of the background imagery is degraded to approximately 12 arc minutes for current systems which is considered insufficient for air-to-ground weapons delivery.

Additional research and/or engineering development is required to provide single raster displays with the required resolution to realistically display small ground and/or airborne targets.

7. Color

Monochrome display on mosaicked CRTs has been successfully demonstrated and evaluated. Scene content, with additional capabilities to the generation system, as previously outlined, will overcome many of the limitations experienced in this evaluation. Additional limitations can be overcome through the use of color displays. As identified by the 2B35 evaluation results, color improves the apparent resolution, allows more natural and accurate identification of ground or airborne objects.

Color makes task loading more realistic by reducing the requirement for pilots to concentrate for an abnormally long time on a specific target. Consequently, targets are identified more naturally by their color contrast.

Research and development in color CRT and inline infinity optic hardware is essential. Color transmission is limited due to the transmission inefficiencies of present optics. Significant improvements in color CRT brightness and/or infinity optics light transmission is required. Mission task performance in the simulator will become closer to flight performance with the addition of color cues.

(9) Required/Optimized Image Generation Performance

(a) Camera Probe

Since the camera probe is the first link in the video generation chain, it must possess the stringent optical properties required to transmit the complex scene generation needed to accomplish air-to-ground weapons delivery. The probe must be capable of passing high resolution imagery over an extremely wide FOV to the camera system without distortion or degradation. The operating FOV needs considerable expansion beyond that demonstrated system (40° diagonal). Further research is needed to determine the minimum AOI. The probe should be capable of operating between a simulated 20,000 foot altitude to the runway eye height of the aircraft being simulated.

The dynamic qualities of the probe head must meet the acceleration rates of the aircraft being simulated (i.e., roll rates, pitch, and yaw accelerations, etc.). The probe must have unlimited freedom in the roll and pitch axis.

The probe should be rugged to avoid serious damage if inadvertent contact with the model board occurs. Probe excursion limits must be controlled by both mechanical and software fail safe protection systems. Miniaturization of the probe head is considered necessary to allow operation in close proximity to mountains and structures.

(b) Camera

The camera should have inherent qualities which will provide both static and dynamic high resolution image output signals in all operating envelopes (i.e., day, night, dusk, high and low altitude). As tested in Phase I and experienced in Phase II, the resolution of the camera in the TMB/Optical Mosaic system was drastically reduced when dynamics were applied to the system. Further research is required to improve the horizontal and vertical resolution characteristics of cameras now available. Research is also required to improve camera response to low light levels if effective dusk and night tasks are to be accomplished.

(c) Background Terrain

Simulation of the sky/earth background supporting cue should be accomplished through use of the Synthetic Terrain Generation (STG) methods. Careful integration of this feature to the AOI to blend and match the horizons is required. STG features which are behind the AOI must be blanked to avoid bleed through. The STG should also incorporate various symbols to provide secondary visual cues.

(d) Moving Targets

Various designs for modeling moving models on the TMB have been theorized. The only viable method appears to be through an insert principle using a separate image generator system (i.e., CIG). The CIG system would be integrated into the camera model video chain and should supply the weapons impact, tracer fire, air-to-ground and ground-to-air missile effects, and all moving targets in the airborne and ground environment. Further research is required to determine the number of images required the best integration design, and to prove the feasibility and utility of the design approach.

4. CIG/LIGHT VALVE PROJECTION SCREEN

Since this evaluation was abbreviated, the previous method of identification of limiting factors was not employed. The following synopsis of results is gleaned from the questionnaire provided the pilots during a one-to-two hour flight. The primary purpose of the 2B35 evaluation was to provide an opportunity for the evaluation pilots to gain experience with a color display system and assess the effects on task performance. Table III-14 contains relevant system characteristics. Significant results are listed with expanded discussion on their effects.

a. Color

Color makes a significant difference in reducing unnatural task loading by providing a more distinguishable target at greater distances. With monochrome systems, time was wasted unrealistically in trying to identify a target. In the opinion of the pilots, depth perception was aided significantly by color. Color also adds realism to the mission. Pilots were unanimous in the opinion that color does not substitute for edge capability. Most felt that the 1000 edges used in this system did not provide enough detail even with color.

IMAGE GENERATOR

Real-Time Data Base Storage	1000 Edges
Scene Update Rate	30 Hertz
Moving Models	3 *
Levels of Detail	8 Models
Total Real-Time Objects Per Scene	256 Objects
Special Purpose Lights	30 Lights
Variable Size Point Light/Point Sources	1024 Lights/Sources
Calculated Video Output	512 Elements, 525 Lines
Real-Time Scene Generation	1024 Edges
Maximum Edge Crossings/Raster Line-System	512
Maximum Edge Crossings/Raster Line-Channel	256
Digital Edge Smoothing	Yes
Variable Fog/Fading	Yes
Aerial Perspective	Yes

DISPLAY SYSTEM

Number of Channels	3
Field of View - Vertical	60° (±30°)
- Horizontal	210° (±105°)
Resolution - Vertical	18.3 Arc Minutes
- Horizontal	19.3 Arc Minutes
Highlight Brightness	2.4 Foot Lamberts (Average)

* Environments not structured for 3 simultaneous moving models for Project 2235 but the system capability exists.

TABLE III-14 - SYSTEM CHARACTERISTICS (2B35)

b. Brightness

The display brightness was by far the best seen during the evaluation. The comment is particularly interesting since other systems had comparable or brighter displays when measured during the Phase I evaluation. Advertised highlight brightness (center of screen) for this sytem is 2.4 foot lamberts.

c. Resolution

Most pilots were quite satisfied with resolution, however, lack of detail due to edge restrictions was a common complaint. An additional comment made was losing fine detail when an object moved rapidly between scan lines. In view of the horizontal and vertical resolutions of this system (19.3 and 18.3 arc minutes per line pair respectively) a phenonmenon of apparent resolution was evident. That is, the system appeared to have much better resolution than could be actually protrayed by the equipment in use. While statistical evidence was not collected which conclusively proved this theory, it is believed that color played a significant role in accomplishing this surprising result.

d. Alignment

Seam alignment and distortion, evident on other systems, was not a factor on this device. The display sceens were noticable to the pilots, but easily ignored and forgotten in the performance of a task.

e. FOV

The 210° X 60° stationary FOV was inadequate to perform most of the tasks. Air-to-ground delivery performance had to be significantly altered due to the excursion of the target beyond the display limits. Pilots were forced to guess on entry to and roll out from turns. It must be pointed out that it was not the size of the AOI that was inadequate, but the stationary aspects of the display. If the 210° X 60° FOV were used as an AOI within an FOV approximating the aircraft, it would have been highly useable.

f. Detail

As previously mentioned, the 1000 edge system does not allow enough edges for surface detail. As a comparison, the 2000 edges with 500 edge buffer on the CIG/Optical Mosaic system evaluated allowed placing buildings, trucks, tractors, etc., at points of advantage in the visual scene (i.e., around the approach end of runway and on the conventional range). This feature provided excellent landmarks for secondary visual cues as well as aiding depth perception. Another promising feature on the 2B35 was the use of the 2000 point light sources. These lights were colored black and were randomly spaced in the gaming area. The effect created was more surface detail. While they were distracting at times, because they tended to flash on and off, once this problem is eliminated, the apparent surface texturing will offer a significant improvement.

g. Software Employment

The 2B35 software employment features a unique capability to switch level of details in real time. This feature is employed to conserve edges and is dependent upon the distance of the aircraft to target areas. This feature was very distracting, since in many instances the target would tend to pop out at extremely close ranges (1000'). It appears that this feature could be worked to great advantage if a smooth transition could occur and the feature was employed at longer ranges.

SECTION IV

COMPARATIVE SUMMARY OF OPTIMIZED SYSTEMS

This section presents a comparison of the optimized systems as described in paragraphs 1b(4), 2b(4), 3b(4) of Section III. A fourth system using CIG and Dome Projection is identified and described in an attempt to include all major image generation and display combinations. The descriptions contained herein do not describe an actual system, rather they are based on the experience and knowledge gained both during the evaluations and in related activities.

1. OPTIMIZED CIG/DOME PROJECTION SYSTEM

Section III contains optimized systems for CIG/Optical Mosaic, TMB/Optical Mosaic, and TMB/Dome Projection System. The fourth option that has potential to simulate air to ground weapons delivery would utilize CIG/Dome Projection Technology. Such a system is hypothesized below based on information obtained during the final reporting phase and not substantiated by Phase II data. The fundamental characteristics of this system were extrapolated from the optimized CIG/Optical Mosaic and TMB/Dome Projection Systems described in Section III.

a. Image Generation

(1) Image Generator Channels

A sufficient number of channels must be provided to input imagery to each projector to supply a sufficiently large AOI or full FOV detailed ground image to permit unaltered pilot task performance. If the AOI is used, it must be slewable through a combination of head and eye movements to permit pilots freedom to detect specific cues within the AOI. In accomplishing a slewable AOI particular attention must be given to AOI overshoot and adverse oscillation. The AOI must be permitted to migrate smoothly and quickly within the total FOV of the aircraft to be simulated. Realistic target migration is essential if continuous adjustments to flight parameters are to be made throughout the task performance envelope. Sufficient channel development is SOA. Research into head/eye slewing is required.

(2) Edges and Level of Detail

A significant increase in the number of displayed edges per cockpit beyond the 2500 demonstrated is required. It is felt that increasing edge capacity will provide the environmental detail necessary to allow unaltered task performance in all mission areas, with emphasis on tactical operations. Such an increase should also help prevent scene breakup due to systems overload, allow more realistic modeling, and permit sufficient modeling to provide a confusion factor for target identification in the target area. This confusion factor is especially important in tactical target environments where contrast ratios, camouflage, item simularity and high stress are competing factors.

An increase in the number of levels of detail is required. The demonstrated three levels of detail concept did not provide smooth enough feature changes which result in distractions to the pilot. The affect of increased levels of detail would result in a smoother visual transition of features into the viewing range of the pilot and thus provide a more realistic scene.

The use of curved surface shading, concentration of edges, and development of texturing and contouring algorithms should be pursued. These features allow far more efficient use of available edges and could improve the modeling capacity of a given system.

(3) Curved Surface Shading

Curved surface shading is considered necessary to allow the CIG System to present solid curved surfaces using a minimum number of edges. This feature provides more realistic modeling of real world objects which are not constructed entirely of flat surfaces. This feature is especially important for constructing aircraft for FAC and formation tasks, and for more realistic ground vertical relief.

(4) Surface Texturing

Surface texturing is required to provide improved altitude and velocity cues during low angle/low altitude tasks. These cues are especially important during low angle weapons delivery (e.g., 10-15° strafe) and are used to determine the proper release point, prevent ground contact, determine ground track, and provide additional flight path and speed cues.

Current technology can only provide these cues through the use of edges (very inefficient) or the use of surface shading point lights (colored black). Light points have been demonstrated and provide a minimal level of texturing. Research and development is required to develop the algorithms to efficiently provide the sufficient surface texturing required for low angle/low altitude tasks.

(5) Point Light Sources

Point light sources are required to simulate the night lighting around an airdrome, urban and rural light patterns, and range lighting including flares. Generation of point lights must not be at the expense of edges. They must be a separate and distinct feature. The light points must be functional with respect to brightness, directionality, range and color/shades of gray.

(6) Multiple Moving Target

Multiple moving models that can be simultaneously displayed are required. These would include vehicles, surface-to-air and air-to-surface missiles and aircraft. These models will allow attacks on moving targets, defensive maneuvers against missiles, formation flight training, mutually supporting ground attack, and FAC operations.

(7) Weapons Effect and Scoring

Weapons effects including ordnance impacts, tracer fire, and target destruction are required to provide visual feedback to the pilot as to the effectiveness of his weapons delivery. Such feedback will allow error analysis prior to the next delivery. This is especially important on the tactical range or for targets of opportunity where the target may not be designated for score.

Accurate weapons trajectory and scoring algorithms are required to properly compute and display weapons effects. Weapons trajectory and scoring computations are normally performed in the host simulator computer not the visual computer but they form an essential part of any weapons delivery simulator.

(8) Weather Effects

The ability to vary ceiling and visibility realistically is required to restrict the envelope around the target in which the pilot may maneuver his aircraft and retain sight of the target. These restrictions substantially increase the task loading on the pilot during tactical weapons delivery and thus more closely approximate inflight task performance.

(9) Day/Dusk/Night Lighting Capability

The lighting conditions must be sufficiently realistic to provide the correct quality of visual cues and to properly task load the pilot so that his performance in the simulator reflects task performance in the aircraft for the conditions simulated.

b. Image Display

(1) FOV

The FOV of the display should approximate that of the aircraft with normal aircraft restrictions such as canopy frames or aircraft surfaces. This would prevent artificial restrictions introduced by the visual display from altering task performance.

(2) AOI Size

The size of the AOI must be substantially larger AOI than the 60° diagonal AOI demonstrated to reduce the head motions required for orientation around the target area and during weapons delivery to allow some eye motion to be used for orientation instead of requiring head motion. This would allow more normal concentration on the target and the weapons delivery with less but more realistic effort retained for overall orientation. The actual required size of the AOI cannot be estimated at this time. No objective data exists to define the size. Research is required in this area.

The major problem with a large AOI is in the display not the image generation area. Some engineering development is required to allow projection of a high resolution wide angle AOI in a dome display. The most promising solution is to utilize multiple projection techniques to make-up the AOI.

As a <u>goal</u>, the necessary engineering development should be pursued to provide a full FOV display of imagery using a matrix of projections within the Dome.

(3) AOI Mechanization

The AOI should be operated in a combination of head slaved and target slaved modes with an automatic transfer between them. This would allow the pilot to locate the target without the AOI pointing it out to him, maneuver about the target freely, and after roll-in, not have to be concerned about head movements to keep the target in the AOI. After weapons release, the AOI would again become head slaved to present its disappearance beneath the aircraft.

The AOI must be accurately synchronized with the background horizon projected by the point light source sky/earth projector and both horizons smoothly track each other within the FOV to prevent disorientation.

(4) Background Imagery

Background horizon/sky/earth imagery is required throughout the FOV of the display outside the AOI to provide peripheral attitude cues to support the AOI. Limited heading cues are necessary and may be provided by mountains on the horizon. Currently a point light source sky/earth projector using spherical transparencies provides the most satisfactory background imagery for a dome system.

(5) Color

Color imagery is desired for the AOI display. Color imagery provides an apparent resolution increase for the pilot over monochrome imagery with the same or degraded measured resolution. The use of color imagery allows more rapid recognition of objects in the scene (because of their familiar colors) than is available from differences in shading alone. The early recognition of objects allows the pilot to use more normal cues for task performance.

The problems associated with color in a TMB/Dome System lie primarily in the display. A color projector is relatively large and its physical size

 (Continued on page IV-11)

Visual System Features	System A CIG Optical Mosaic		System B CIG Dome Projection		System C TMB Optical Mosaic		System D TMB Dome Projection	
	Gen	Dis	Gen	Dis	Gen	Dis	Gen	Dis
Large FOV	-	L	-	L	-	L	-	L
Area of Detailed Imagery:								
Large AOI	L	L	L	M	M	NP	M	M
Full FOV Imagery	L	L	L	H	H	H	H	H
AOI Control/CIG Detail Concentration								
Target Fixed	L	L	L	L	L	L	L	L
Head Slaved	L	L	L	L	L	L	L	L
Head and Eye Slaved	L/M	L	L/M	L/M	L/M	L	L/M	L/M
Combined Target and Head Slaved	L	L	L	L	L	L	L	L
Image Characteristics								
Color	L	H	L	*1	L	H	L	*1
Usable Image Brightness	L	L	L	L	L	L	L	L
High Resolution (1-3 arc-min)	L	H	L	H	H	H	H	H
Medium Resolution (6-7 arc-min)	L	L	L	L	L	L	L	L
Low Display Distortion	-	L/M	-	L	-	L/M	-	L
Coarse Image Detail	L	L	L	L	L	L	L	L
Fine Image Detail	H	L	H	L	L	L	L	L
Texture	H	L	H	L	L	L	L	L
AOI Background Characteristics								
Featureless	-	-	L	L	L	L	L	L
Low Detail Dynamics	-	-	L	H	L	L	L	H
Low Detail Correlated	-	-	L	H	L	L	L	H
Moving Model								
High Resolution (1-3 arc-min)	L	H	L	L	L	H	L	L
Single - Ground	L	L	L	L	L/M	L	L/M	L
Multiple - Ground (2-4)	L	L	L	*2	L/M	L	L/M	*2
Single - Air	L	L	L	*2	L	L	L	*2
Multiple - Air (2-4)	L	L	L	*2	L	L	L	*2

Table IV-1 COMPARATIVE ANALYSIS

	System A		System B		System C		System D	
	Gen	Dis	Gen	Dis	Gen	Dis	Gen	Dis
Gaming Area (*3):								
Large Gaming Area	L	-	L	-	L	-	L	-
Multiple Gaming Areas	L	-	L	-	L	-	L	-
Flexible Gaming Area	L	-	L	-	*3	-	*3	-
Flight Maneuvering:								
Unrestricted Lateral Proximity (within 50')	L	-	L	-	M	-	M	-
Unrestricted Vertical Proximity (within 10')	L	-	L	-	*4	-	*4	-
Unrestricted Pitch Capability	L	-	L	-	L	-	L	-
Special Effects:								
Weapon Impact	L	L	L	L	M	M	M	M
Weapon Scoring	L	-	L	-	M	-	M	-
AGM, SAM, Flak (AAA) Tracer Fire	L	L	L	*2	M	L	M	*2
Visibility Restriction	L	L	L	L	L	L	L	L
Visible Ceiling	L/M	L/M	L/M	L/M	L/M	L/M	L/M	L/M
Day/Night/Dusk Lighting	L	L	L	L	L	L	L	L
Cultural Lighting	L	L	L	L	L	L	L	L

Symbols
- - = Not applicable.
- L = Low Risk
- L/M = Low to medium risk
- M = Medium Risk
- H = High Risk
- NP = Not technically practical

Table IV-1 COMPARATIVE ANALYSIS (continued)

NOTES:

1. The use of color imagery in a dome display is low risk for large (e.g., 20 ft radius) domes but high risk for small (e.g., 10 ft radius) due to the physical size of current color projectors and the problems associated with mounting such a projector in a dome.

2. Providing moving models outside the AOI in a dome display is a function of dome size. For large (20 ft radius) domes, two independent high resolution models may be provided. For small (10 ft radius) domes no independent moving models outside the AOI can be provided.

3. The use of TMBs to provide large or multiple gaming areas is low risk. The size and number of TMBs is restricted however by cost and facility constraints.

4. The vertical proximity of the simulated aircraft to the TMB surface is low risk if a large scale TMB is used to meet the low altitude requirement and a small scale TMB is used to meet the high altitude requirement. If a single TMB is to be used to meet the overall altitude requirements, however, the risk is high.

TABLE IV-1 TERMS EXPLAINED

Large FOV - That field of view which is either filled with imagery (e.g., CIG/CRT) or in which a large AOI is allowed to migrate (e.g., TMB/CRT).

AOI Control/Edge Concentration - The method employed to drive the AOI, or the area in which the maximum number of edges is concentrated.

Image Characteristics - Combines generated and display characteristics, (i.e., fine detail). Details such as trees, ground texturing, contours.

AOI Background Characteristics -

a. Featureless - Similar to Sky/Earth Projectors, Blue Sky/Green Earth.

b. Low Detail Dynamic - Checkerboard ground pattern with symbols; able to provide airspeed and altitude cues.

c. Low Detail Correlated - Limited CGI with camera model insert.

Moving Models - High Resolution (1-3 arc-min) Moving Model. High Resolution Ground or Airborne, independently moving object.

Single Moving - Ground - Low Resolution (6-7 arc-min) ground target, (i.e., truck, tank).

Multiple Moving Target - Ground. Low Resolution, independently/simultaneously moving trucks, tansk, etc.

Single Moving Model - Air - A single independently moving, low resolution airborne object (e.g., aircraft, SAM, AGM) displayed simultaneously with the detailed imagery.

Multiple Moving Models - Air - Two to four independently moving, low resolution airborne objects displayed simultaneously with the detailed imagery.

Gaming Area - The area of detailed imagery within which missions may be conducted.

Large Gaming Area - A gaming area of sufficient size and consisting of cultural and geographic information of sufficient detail to permit navigation and tactical tasking over an extended period of time (i.e., 1.5 hours) without duplication of information.

Multiple Gaming Areas - Multiple unique gaming areas as defined above.

Flexible Gaming Area - A gaming area in which the features may be easily altered to meet changing mission requirements.

Flight Maneuvering - The ability to fly the aircraft within the gaming area with minimum restriction imposed by the visual system. This includes being able to fly within 50 ft. laterally of a mountain or similar object, within 10 ft. of the ground, or without an imposed pitch limitation.

Weapons Impact - A visually displayed indication of the location of a weapon impact on the detailed imagery.

Weapons Scoring - The ability to compute the location of a weapons impact relative to a target.

AGM, SAM, Flak, Tracer Fire - The indication of the flight path of surface-to-air or air-to-surface weapons.

Visibility Restriction - Provide realistic restrictions to flight visibility.

Ceiling - Generate and display a cloud ceiling which will allow a pilot to tell his distance below the ceiling.

Day/Night/Dusk Lighting - Sufficiently control ambient lighting to realistically simulate day, night, dusk conditions.

Cultural Lighting - Provide proper air field and surrounding manmade lighting.

makes it hard to accommodate in a small dome without overly restricting the FOV. Projector size becomes less of a rectriction as the dome radius becomes larger. The weight of the projector is also a problem for the demonstrated 5 DOF Beam Motion System but not for other types of motion systems.

(6) Day/Dusk/Night Capacity

The display must be capable of presenting a dusk and night lighting in addition to daylight conditions. The projector must respond to low light levels with little loss of resolution and minimum delay to clearly present night scenes and lighting without streaking.

2. COMPARATIVE SUMMARY OF OPTIMIZED SYSTEMS

The four optimized systems, fundamental visual system features, and estimated technical risk associated with the feature are listed in Table IV-1.

This table is representative of the features considered necessary to allow performance of air-to-ground tasks. A comparison of the four systems follows:

a. Large FOV

All systems can provide a large FOV with low risk.

b. Area of Detailed Imagery

System A can readily generate and display full FOV imagery.

Systems B and D may provide a sufficient AOI at medium risk. System C can possibly provide a detailed scene of sufficient size to allow unaltered task performance but at high risk and great expense. System C is therefore not considered a viable candidate.

c. AOI Control

All systems can allow adequate control of the AOI with low to medium risk.

d. Image Characteristics

Color is a low risk feature for Systems B and D. Usable image brightness on Systems A and C, which incorporate optical mosaics, make the addition of color on these systems high risk.

Visible image brightness, medium resolution, and course image detail are low risk features for all systems. High resolution is high risk on all systems due chiefly to display limitations. Fine image detail and texture are considered high risk for Systems A and B due to the finite edge limitations of CIG and lack of an adequate texturing algorithm.

For Systems C and D detail and texturing are considered low risk.

e. AOI Background Characteristics

An AOI background is not required for the full FOV imagery system (System A). A featureless background can be added to Systems B, C, and D with low risk. The addition of a low detail dynamic background and/or low detailed correlated background characteristic to Systems B and D would be high risk due to the need for additional projectors. These features could be readily added to System C.

f. Moving Models

Generation of moving models is low risk for Systems A and B. It is low to medium risk on Systems C and D due to the difficulty of correlating an inserted image with a TMB. Display of a high resolution model in Systems A and C is high risk due to display resolution limitations of 5 to 7 arc-minutes. High resolution of a moving model in Systems B and D is low risk due to the application of independent projectors which use a raster shrinking technique. Display of a single moving model on the ground is considered low risk. Display of a single moving model in the air or multiple moving models on the ground or in the air is low risk for Systems A and C and low risk for Systems B and D (assuming that a large dome is employed).

g. Gaming Area

Large and multiple gaming areas are considered low technical risk for all systems. However, the application of large and numerous gaming areas for Systems C and D must consider cost and facility constraints.

Flexible gaming areas that are unlimited, easily amended, easily modified, and readily interchangeable are low risk in Systems A and B. The gaming areas for Systems C and D are hardware limited and therefore offer limited flexibility.

h. Flight Maneuvering

Systems A and B have almost no restrictions on horizontal travel and no vertical restriction, or pitch restrictions in relation to the gaming area.

The horizontal proximity for Systems C and D is restricted by optical probe head size. Overcoming this limitation is medium risk. Vertical proximity for Systems C and D is unrestricted only if multiple TMBs of different scales are used. Unrestricted pitch capability is low risk for Systems C and D.

i. Special Effects

Weapons impact and scoring are low risk for Systems A and B. Weapons scoring and subsequent display of weapons impact is medium risk for Systems C and D due to TMB image correlation problems. All systems can provide visibility restrictions, day/dusk/night lighting, and cultural lighting at low risk. Generation and display of ceiling conditions is low to medium risk for all systems, with the risk depending on realism of the simulation due to the demonstrated difficulties encountered in realistically simulating a cloud layer in optical mosaic displays and the difficulties in realistically generating a ceiling condition with the TMB Technology.

j. Air to Ground Missile (AGM), SAM, Flak and Tracer Fire

Simulation of these effects are low risk for System A. Image generation for these effects are low risk for System B and medium risk for Systems C and D (due to TMB image correlation problems). Display of these effects in dome systems (Systems B and D) is low assuming the use of a large dome.

Display in System C is low risk.

SECTION V

CONCLUSIONS

Conclusions expressed below are based on the results presented in Section III and deduced from the analysis contained in Section IV.

1. CONCLUDE

a. State of the Art

Visual air-to-ground weapons delivery simulation was successfully demonstrated with SOA technology. Operational utility of the simulations vary between technologies (reference Section III).

b. CGI/Optical Mosaic Technologies

A system utilizing computer-generated imagery presented to the pilot through an inline infinity optical mosaic display provided satisfactory visual cues, had a sufficient FOV, and possessed the flexibility essential for air-to-ground tasks accomplishment. The operational evaluation (Phase II) of this technology revealed that pilots performance of all controlled range weapons deliveries and many tactical weapons delivery tasks could be accomplished without alteration when compared to actual inflight task performance. It is estimated however that with the addition of the following features, reported system limitations or anomalies will be alleviated and thus the CIG/Optical Mosaic System can be optimized:

(1) Low Risk

(a) A significant increase in edge processing capability to provide enriched environments.

(b) The reduction of image distortions caused by optical window seams.

(2) Medium Risk (Engineering Development)

(a) An increase in the resolution capability of the display system.

(b) The generation and display of more realistic cloud ceiling conditions than what was evaluated (Reference Section III, paragraph 1b(2)(a)4, p. III-17).

(3) *High Risk (Research and Development)

(a) The generation and display of surface texture with a minimal use of edges.

(b) The display of color imagery.

*NOTE: Inclusion of R/D Items are not required to provide a usable system. These are included to optimize the CIG/Optical Mosaic Approach. Ground texturing algorithms should be included in this system when perfected.

c. TMB/Dome Projection

A system utilizing terrain model board imagery displayed through a real image projector system on a spherical dome provides marginal utility for use during air-to-ground weaponry task performance. Significant improvements in image generation technologies (i.e., probe, camera, scaling techniques) and image display technologies (i.e., AOI size and associated high resolution, background, weapon effects, special effects) are required before this approach can be successfully employed. A careful analysis of potential systems capabilities must be accomplished to assess long term benefits before research and development resources are allocated to improving this approach.

d. TMB/Optical Mosaic

A system utilizing terrain model board imagery presented to the pilot through an optical mosaic display cannot be used to satisfactorily perform air-to-ground weaponry tasks due to formative technical limitations and associated high risk engineering corrections. TMB/Optical Mosaic technology should not be pursued for application of the air-to-ground mission. Further evaluation of this approach is recommended only if significant technical advancements are achieved from independent research efforts.

e. CIG/Dome Projection

A system utilizing computer generated imagery displayed through a real image projection system on a spherical dome can potentially allow the performance of air-to-ground weapons delivery tasks. In addition, this approach has the potential to simultaneously display high resolution air-to-air targets and high resolution ground imagery for both air-to-air and air-to-ground tasks performance (Reference Section III, paragraph 1b2,(a),8, p. III-19 for limitations of Optical Mosaic display). CIG/Dome Projection cannot be considered a near term solution to the air-to-ground weapons delivery problem due primarily to the lack of a sufficiently large AOI capability or display of detailed ground imagery throughout the entire FOV. The following capabilities will require research and/or engineering development in order to optimize the potential of this system:

(1) A high resolution, wide angle projection system capable of providing the large AOI or full FOV containing the ground imagery necessary for the accomplishment of air-to-ground tasks. Detailed ground imagery throughout the full FOV should be considered as the ultimate design goal.

(2) Improved edge processing capability, addition of surface texture, and correct simulation of ceiling conditions as developed for the CIG/Optical Mosaic system.

(3) The display of a low detail dynamic background in the event that full FOV imagery cannot be achieved.

(4) The simultaneous display of air-to-air and air-to-ground targets in a high-gain, spherical dome of optimum size.

(5) The display of color imagery.

SECTION VI

RECOMMENDATIONS

As a result of this project, the following actions are recommended:

a. Initiate a program that will provide a production prototype CIG/Optical Mosaic system in a cost effective manner. The system should have expanded capability to fulfill as many A-10 operational requirements as possible. The prototype should incorporate low risk improvements with medium and high risk improvements as design goals (reference Section V, paragraph 1.b p. V-1). As results of medium and high risk development efforts are achieved, they should be evaluated by program management personnel for compatibility with requirements and program milestones and incorporated into the following descriptive characteristics:

(1) Two-cockpit configuration with a shared CIG system.

(2) Enriched ground environment.

(3) Multiple moving models.

(4) Monochrome display.

(5) Special efforts (reference Section IV, Table IV-1 for listing).

b. Pursue research and development efforts in the following areas:

(1) Initiate an effort with sufficient priority to evaluate the engineering feasibility of developing a prototype CIG/Dome Projection System (with enriched ground environment throughout the FOV or optimum size AOI). Sufficiently high priority should be placed on this effort because of its potential to provide for simultaneous performance of air-to-ground and air-to-air tasks (reference Section V, paragraph e and Section IV, paragraph 1 for details).

(2) Ground Texturing in CIG environments.

(3) Optical window optimized for color transmission.

(4) Definition of the optimum size of an AOI which would allow for unaltered task performance.

BIBLIOGRAPHY

Basinger, James D. "An Approach to Computer Image Generation for Visual Simulation," AIAA Visual and Motion Simulation Conference, Paper No73-928, September 1973.

Bell, Frank C., ASUPT Technical Fact Sheet USAF Human Resources Labratory, Flying Training Division, Williams AFB, Arizona 85224, May 1974.

Kugel, D.L. and Gressang, R.V., "Air-to-Ground Visual Display System," AIAA Visual and Motion Simulation Conference, Dayton, Ohio, 26-28 April 1976.

Kugel, D.L. and Gressang, R.V. "Air-to-Ground Visual Display System," 12th Annual Conference on Manual Control, University of Illinois, May 1976.

Monroe, Eric G. "Air-to-Surface Weapons Delivery Simulation With a Computer-Image Generation System, Modeling and Simulation" 1976.

Monroe, Eric G. Environmental Data Base Development Process for the ASUPT CIG System, AFHRL-TR-75-24, August 1975

Monroe, Eric G., "Computer Image Generation in Visual Flight Simulation," Modeling and Simulation, 1975 edition, Vol 6-Part I, page 475.

Monroe, Eric G., et al, ASUPT Visual Simulation of Air-to-Surface Weapons Delivery, AFHRL-TR-76-40-1976.

Schwing, R.L., The Man-Rating Associated with the AFFDL LAMARS, AIAA Visual and Motion Simulation Conference, Dayton, Ohio, 26-28 April 1976.

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